Mineral Development Division
Department of Mines and Energy
Government of Newfoundland and Labrador

MEMOIR 1

GEOLOGY OF THE CARBONIFEROUS BAY ST. GEORGE SUBBASIN, WESTERN NEWFOUNDLAND

BY IAN KNIGHT

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PREFACE

This report presents the first comprehensive description of the geology of the Carboniferous strata of the Bay St. George subbasin in southwestern Newfoundland. It results from systematic 1:50,000 mapping and detailed stratigraphic studies carried out between 1974 and 1978. The project was prompted by the discovery of base metal mineralization in the area in 1973, the delineation of a major Pb-Zn deposit in Carboniferous rocks at Gays River in Nova Scotia, the presence of gypsum and salt, and the general lack of detailed geological mapping in the area.

The memoir provides a detailed description of the lithostratigraphy of the Bay St. George Carboniferous, an interpretation of the tectonic setting of sedimentation and of depositional environments, an analysis of the structural history of the area and an assessment of the mineral potential.

This is the first in Mineral Development Division's memoir series. Further publications in this series will be provided as geological investigations are completed in major geological regions of Newfoundland and Labrador.

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Director,
Mineral Development Division,
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TABLE OF CONTENTS

PAGE

ABSTRACT

CHAPTER 1

INTRODUCTION

Geographical Setting.. 1
Regional Geological Setting.. 5
Local Geological Setting... 9
Previous Work... 10
History of the Present Investigation.................................... 11
Aims of Study... 12

CHAPTER 2

STRATIGRAPHY

Part 1 - Introduction and Stratigraphic Problems.............. 13
Part 2 - Anguille Group.............................. 13
Distribution.. 14
Thickness... 14
Description of Formations... 14
- Kennels Brook Formation... 14
  - Definition, distribution and thickness............................. 14
  - General lithology.. 16
    - (A) *GRAY-GREEN SANDSTONE AND CONGLOMERATE*........................ 16
    - (B) *GREEN TO RED SANDSTONES AND SLATES*............................ 17
    - (C) *BROWN MUDSTONES AND SANDSTONES*................................ 17
  - Age and correlative deposits....................................... 18
  - Depositional environment... 18
- Snakes Bight Formation.. 19
  - Definition and distribution.. 19
  - Thickness.. 20
  - General lithology.. 20
    - (A) *BLACK MUDSTONE - SHALE LITHOFACIES*............................ 21
    - (B) *GRADED SANDSTONE/SILTSTONE - SHALE LITHOFACIES*............... 24
    - (C) *THICK BEDDED SANDSTONE LITHOFACIES*............................ 26
    - (D) *THINLY BEDDED SANDSTONE-SHALE LITHOFACIES*..................... 27
    - (E) *INTRAFORMATIONAL MIXTITE LITHOFACIES*.......................... 27
    - (F) *CARBONATE LITHOFACIES*... 29
  - Paleocurrents.. 31
  - Age and correlative deposits....................................... 31
  - Depositional environment... 31
- Friars Cove Formation... 36
  - Definition and distribution.. 36
  - Thickness.. 37
  - General lithology.. 37
    - (A) *CONGLOMERATE - PEBBLY SANDSTONE LITHOFACIES*................... 40
    - (B) *THICK BEDDED SANDSTONE LITHOFACIES*............................ 46

(C) *RIPPLED SANDSTONE LITHOFACIES* 49
(D) *SHALE-SANDSTONE LITHOFACIES* 50
(E) *RED SANDSTONE AND PEBBLY ARKOSE LITHOFACIES* 54
(F) *CARBONATE LITHOFACIES* 55
(G) *WELL SORTED SANDSTONE - SILTSTONE LITHOFACIES* 57
Paleocurrents 57
Age and correlative deposits 59
Depositional environment 59
Spout Falls Formation 61
Definition and distribution 61
Thickness 62
General lithology 62
(A) *THICK BEDDED SANDSTONE LITHOFACIES* 63
(B) *STRATIFIED SANDSTONE LITHOFACIES* 65
(C) *FINING-UPWARD SANDSTONE-SILTSTONE LITHOFACIES* 66
(D) *SANDSTONES WITH LARGE SCALE CROSSBEDS* 67
(E) *SILTSTONE-VERY FINE SANDSTONE LITHOFACIES* 68
(F) *CONGLOMERATE LITHOFACIES* 68
Paleocurrents 68
Age and correlative deposits 68
Depositional environment 69
Petrography of the Siliciclastics of the Anguille Group 70
Age and Correlative Deposits of the Anguille Group 72
Summary and Geological History of the Anguille Group 73
Part 3 - Codroy Group 83
Introduction and Definition 83
Distribution 83
Description of Formations 85
Ship Cove Formation 85
Definition and distribution 85
Thickness 85
General lithology 85
(A) *STRATIFIED PACKSTONE LITHOFACIES* 86
(B) *LAMINITE LITHOFACIES* 93
(C) *MOLDIC ARGILLACEOUS AND SHALY LAMINITE LITHOFACIES* ... 98
(D) *INTRAFORMATIONAL LIMESTONE BRECCIA LITHOFACIES* 100
(E) *OOLITIC LIMESTONE LITHOFACIES* 101
(F) *SANDSTONE LITHOFACIES* 101
(G) *OTHER ROCK TYPES* 103
Paleontology, age and correlative deposits 103
Depositional environment 103
Codroy Road Formation 106
Definition and distribution 106
Thickness 106
General lithology 106
(A) *RED SILTSTONE AND SANDSTONE LITHOFACIES* 107
(B) *MULTICOLORED LAMINATED SILTSTONE LITHOFACIES* 107
(C) *GRAY EVAPORITIC SHALE LITHOFACIES* 108
(D) *GRAY AND BLUE-BLACK MUDSTONE AND SILTSTONE LITHOFACIES* 108
(E) *EVAPORITE LITHOFACIES* 109
(F) *CARBONATE LITHOFACIES* 113
Paleontology, age and correlative deposits 119
Depositional environment 121

Robinsons River Formation 122
Definition and distribution 122
Thickness 124
General lithology 124
Jeffrey's Village Member 124
Highlands Member 127
Mollichignick Member 127
Overfall Brook Member 128
Description of lithofacies 128
(A) *SILTSTONE LITHOFACIES* 128
(B) *FINE SANDSTONE LITHOFACIES* 130
(C) *PLANAR STRATIFIED SANDSTONE LITHOFACIES* 132
(D) *THICK GRADED AND UNGRADED SANDSTONE LITHOFACIES* 134
(E) *PEBBLY ARKOSIC SANDSTONE - MUDDY SANDSTONE LITHOFACIES* 138
(F) *CALICHE LIMESTONE LITHOFACIES* 145
(G) *INTRAFORMATIONAL CONGLOMERATE LITHOFACIES* 153
(H) *GRAY, CARBONACEOUS AND MICACEOUS MUDSTONE - SILTSTONE LITHOFACIES* 154
(I) *INTERCALATED CALCAREOUS MUDSTONE-CARBONATE-MICACEOUS SANDSTONE LITHOFACIES* 156
(J) *PEBBLY MUDSTONE LITHOFACIES* 158
(K) *RED SHALY SILTSTONE LITHOFACIES* 159
(L) *BEDDED MUDSTONE - SILTSTONE/SANDSTONE-CARBONATE LITHOFACIES* 162
(M) *GRAY SHALE/MUDSTONE - SILTSTONE/SANDSTONE LITHOFACIES* 166
(N) *VARICOLORED MUDSTONE LITHOFACIES* 170
(O) *HALITE-BEARING SILTSTONE-SANDSTONE LITHOFACIES* 172
(P) *GREEN-GRAY MUDSTONE-SILTSTONE LITHOFACIES* 174
(Q) *CROSSBEDDED SANDSTONE LITHOFACIES* 175
(R) *MARINE CARBONATE LITHOFACIES* 179
(S) *EVAPORITE LITHOFACIES* 199
Paleocurrents of the Robinsons River Formation 202
Paleontology, age and correlative deposits 203
Depositional environment 208
Jeffrey's Village and Highlands Members 209
Mollichignick and Overfall Brook Members 217
Woody Cape Formation 220
Definition and distribution 220
Thickness 221
General lithology 221
(A) *SHALE LITHOFACIES PLUS ASSOCIATED BEDS* 221
(B) *MASSIVE SILTY MUDSTONE LITHOFACIES* 224
(C) *LAMINATED MUDSTONE-SILTSTONE LITHOFACIES* 224
(D) *INTERBEDDED MUDSTONE-SILTSTONE/SANDSTONE LITHOFACIES* 226
(E) *SHEET SILTSTONE-SANDSTONE LITHOFACIES* 228
(F) *THICK SANDSTONE LITHOFACIES* 229
(G) *RED SANDSTONE LITHOFACIES* 230
(H) *CARBONATE LITHOFACIES* 230
Paleocurrents 232
Paleontology, age and correlation 233
Depositional environment 233

Petrography of the Codroy Group Siliclastics.......................... 235
  Ship Cove and Codroy Road Formations.............................. 235
  Robinsons River Formation.. 236
    Lower Jeffrey's Village Member................................... 236
    Upper Jeffrey's Village Member and Highlands Member.............. 236
    Brow Pond lentil... 237
    Mollichignick and Overfall Brook Members......................... 238
  Woody Cape Formation... 238
  Interpretation of the petrography of the Codroy Group.............. 239
Age and Correlative Deposits of the Codroy Group...................... 240
Paleogeography and Tectonic Setting of the Codroy Group............... 240
Part 4 - Barachois Group.. 248
Definition and Distribution... 248
Thickness... 249
General Lithology... 250
    Description of Lithofacies....................................... 251
      (A) *THICK SANDSTONE LITHOFACIES*.............................. 251
      (B) *RED SILTSTONE LITHOFACIES*................................ 258
      (C) *GRAY TO BLACK MUDSTONE-SHALE LITHOFACIES*................. 259
      (D) *COARSENING-UPWARD GRAY SHALE TO SANDSTONE LITHOFACIES*.... 260
      (E) *COAL LITHOFACIES*... 262
      (F) *BROWN CONGLOMERATE - SANDSTONE LITHOFACIES*............... 262
Paleocurrents... 265
Petrography of the Siliciclastics..................................... 267
    Searston Formation, Codroy lowlands.............................. 267
    Marginal deposits, Trainvain Brook............................... 268
    Sandstones, St. George's Bay lowlands............................ 268
Paleontology, Age and Correlative Deposits............................ 268
Depositional Environment.. 270

CHAPTER 3

STRUCTURE AND METAMORPHISM.. 273
Part 1 - Structure.. 273
Introduction.. 273
Northeasterly Trending Folds.. 273
  Anguille anticlinorium and folds beneath Bald Mountain............. 273
  Flat Bay anticline... 274
  Barachois synclinorium... 274
  St. David's syncline... 275
Thrust Faults and Décollement Zones................................... 275
Other Faults.. 276
  Northeasterly trending faults...................................... 276
    Long Range fault... 276
    Snakes Bight fault... 277
    Others... 280
  Northwesterly trending faults...................................... 280
  Easterly trending faults... 280
    Stormy Point fault... 280
    Shoal Point fault.. 281

Interpretation of Structure.. 281
    The Anguille anticline.. 282
    Northeasterly trending synthetic faults....................... 282
    Northwesterly trending antithetic faults...................... 285
    Easterly trending faults...................................... 285
Age and Regional Controls of Deformation.......................... 285
Structural Conclusions.. 286
Part 2 - Metamorphism... 287

CHAPTER 4

ECONOMIC GEOLOGY.. 288
Part 1 - Base Metals and Associated Industrial Minerals........... 288
Introduction.. 288
Description... 288
    Anguille Group occurrences.................................... 288
    Codroy Group occurrences...................................... 293
        Occurrences in the Ship Cove Formation and the immediately underlying sediments of the Anguille Group.................. 293
        Occurrences near the northern margin of the Bay St. George subbasin and Port au Port Peninsula........................ 296
        Other showings.. 298
Base Metal Potential in the Bay St. George Subbasin............... 298
Part 2 - Evaporites... 298
Gypsum - Anhydrite.. 298
Celestite... 300
Salt deposits... 300
    History of investigation...................................... 300
    Description... 301
    Interpretation.. 307
    Summary... 307
Part 3 - Coal... 308
General Description... 308
Coal in the Codroy Valley... 308
St. George's coalfields... 309
Part 4 - Uranium and Associated Minerals.......................... 310
Description of Uraniferous Rocks.................................. 310
    Mollichignick Member.. 310
    Overfall Brook Member... 311
    Copper Mineralization... 311
Prospective Uranium Areas, Based on Uranium Geochemical Surveys... 312
Uranium Potential in the Bay St. George Subbasin.................. 312

CHAPTER 5

SUMMARY AND CONCLUSIONS... 314
Creation and Early Evolution of the Bay St. George Subbasin....... 314
        Structural evolution of the subbasin during deposition of the Anguille and early Codroy Group............................. 314
        Structural evolution of the subbasin during the deposition of the Codroy and Barachois Group.............................. 315

History of Sedimentation.. 315
Anguille Group.. 315
Codroy Group.. 316
Barachois Group.. 318
Deformation.. 318
Mineralization.. 319
ACKNOWLEDGEMENTS.. 319
REFERENCES CITED.. 320

LIST OF FIGURES

Page

Figure 1: Generalized distribution of onshore Carboniferous strata and surrounding basement rocks in Newfoundland and the Maritime Provinces.................................... 2

Figure 2: Distribution map of subbasins and highs that form the Carboniferous Maritimes Basin in Atlantic Canada........ 3

Figure 3: Major geomorphological subdivisions of the Bay St. George subbasin.. 4

Figure 4: Distribution of groups in the Bay St. George subbasin... 15

Figure 5: Type section of the Snakes Bight Formation.............. Foldout A

Figure 6: Line drawing from photographs of cliffs overlooking Snakes Bight.. 25

Figure 7: Paleocurrent distribution in the Snakes Bight Formation... 32

Figure 8: Type section of the Friars Cove Formation and incomplete section of Spout Falls Formation........................ Foldout A

Figure 9: Sections measured through conglomerate - sandstone lithofacies at the base of the Friars Cove Formation.... 38

Figure 10: Detailed sections through basal conglomerates of the Friars Cove Formation at Cape Anguille.................. 39

Figure 11: Detailed sedimentary sections of lithofacies in the Friars Cove Formation................................ Foldout A

Figure 12: Sections illustrative of lithofacies E and lithofacies G of the Friars Cove Formation......................... 53

Figure 13: Paleocurrent distributions in the Friars Cove Formation... 58

Figure 14: Detailed sedimentological sections in the Spout Falls Formation... 64

Figure 15: Possible tectono-stratigraphic model for the Bay St. George subbasin during the deposition of the Anguille Group... 76-77

Figure 16: Main faults, distribution of geologic terranes and Carboniferous sedimentary basins associated with the Cabot Fault system in western Newfoundland............. 80

Figure 17: Map and cross-sections illustrating main geologic structures, displaced terranes and basin-fills believed to have influenced the Bay St George subbasin as it evolved as a pull-apart basin during the Late Devonian and Early Carboniferous.................................. Foldout B

Figure 18: Sections through the Ship Cove Formation................ 88-89

Figure 19: Detailed section of the Ship Cove Formation on Codroy Island.. 90

Figure 20: Sections compiled for the Jeffrey's Village and Highlands Member of the Robinsons River Formation.................. Foldout C

Figure 21: Type sections of the Mollichignick and Overfall Brook Members of the Robinsons River Formation................. Foldout C

Figure 22: Type section of Overfall Brook Member, Robinsons River Formation... Pocket

Figure 23: Detailed sedimentary sections of nonmarine lithofacies in the redbeds of the upper part of the Jeffrey's Village Member... Foldout D

Figure 24: Detailed sections of the redbeds from the Highlands Member... Foldout D

Figure 25: Detailed sedimentary sections of fluvial sequences in the Mollichignick Member................................... Foldout D

Figure 26: Sections in lacustrine deposits of the Mollichignick Member... Pocket

Figure 27: Detailed sedimentological sections in lithofacies K, L, M and Q, Mollichignick Member........................... Pocket

Figure 28: Detailed sedimentological sections in lithofacies M and T, in the Jeffrey's Village Member..................... 164-165

Figure 29: Detailed sedimentary sections in the lower part of the Jeffrey's Village Member................................. Pocket

Figure 30: Notebook sketches of structures in lithofacies Q sandstones of the Jeffrey's Village Member.................. 177

Figure 31: Carbonate and evaporite units of the Jeffrey's Village Member St. George's Bay lowlands....................... 180A

Figure 32: Paleocurrent data for different members and non-marine and marine lithofacies of the Robinsons River Formation. 204-205

Figure 33: Partly speculative isopach map of the Bay St. George subbasin during deposition of the lower part of the Robinsons River Formation................................ 211

Figure 34: Possible reconstruction of the paleogeography of the northern part of the Bay St. George subbasin during the deposition of the Jeffrey's Village and Highlands Members of the Robinsons River Formation................ 212

Figure 35: Probable paleogeography of Mollichignick Member, Robinsons River Formation and the Woody Cape Formation.. 218

Figure 36: Generalized section of the Woody Cape Formation type section north of Woody Cape and an incomplete section in Capelin Cove.. Foldout E

Figure 37: Detailed sections of intervals of the Woody Cape Formation.. Foldout E

Figure 38: Paleocurrents and type section through the Searston Formation.. Foldout F

Figure 39: Stratigraphic section of marginal conglomerate facies in the Searston Formation, of Trainvain Brook.............. 249

Figure 40: Detailed sedimentary sections of rock sequences in the Searston Formation near Kennedy Point.................. 252-253

Figure 41: Notebook sketches of cliff section in the Searston Formation at Northwest Cove............................. 254

Figure 42: Structural map of the Bay St. George subbasin........... 276A

Figure 43: Structural cross-sections across the Bay St. George subbasin.. 278-279

Figure 44: Map of localities of mineral showings tabulated in Table 14... 289

Figure 45: Distribution of gravity lows in the St. George's Bay lowlands.. 302

Figure 46: Sections compiled from logs of drill hole through St. Fintans, Robinsons and Fischells Brook salt deposits.... 303

Figure 47: Residual gravity and simplified structural cross-sections of three salt deposits in the St. George's Bay lowland.. 306

LIST OF TABLES

Table 1: Stratigraphic nomenclature and subdivisions of previous workers compared to terminology of present work......... 7

Table 2: Compilation of stratigraphic units and lithology from the Moncton, Horton and Anguille Groups in the Maritimes Basin.. Pocket

Table 3: Compilation of stratigraphy, sedimentation and inferred tectonic events in the Carboniferous Bay St. George subbasin and surrounding areas.......................... 74

Table 4: Lithologies and depositional environments of formations in the Codroy Group.................................. 84

Table 5: Compilation of available geological data for the Ship Cove Formation.. 87

Table 6: Compilation of fossil faunas from the main fossiliferous horizons in the Codroy Road Formation and the Jeffrey's Village Member of the Robinsons River Formation......... 120

Table 7: Tabulated summary of distribution and characteristics of lithofacies in the members of the Robinsons River Formation.. 125

Table 8: Pebble lithologies recorded in members of the Robinsons River Formation.. 143

Table 9: Fauna and microflora compiled for the Mollichignick Member (Robinsons River Formation) and the Woody Cape Formation.. 207

Table 10: Correlation of rock units in the Codroy Group western Newfoundland and the Windsor Group, Nova Scotia......... 241

Table 11: Miospore assemblages from the Searston Formation and upper coal-bearing sequence, Codroy Valley.............. 269

Table 12: Orientation of folds and faults in the Bay St. George subbasin.. 283

Table 13: Summary of angular relationship of faults and folds in the Bay St. George subbasin, with comparison to geometry of wrench fault systems outlined by Wilcox et al., (1973)... 284

Table 14: Summary of mineral showings and deposits in the Bay St. George subbasin...................................... 290-292

Table 15: Summary of thickness and chemistry of K-rich zones in salt deposits of the St. George's Bay lowlands shown in Figure 46.. 305

LIST OF PLATES

Page

Plate 1: Cliff section just north of Low Brook, Snakes Bight..... 21

Plate 2: Lithofacies A black shale and laminated mudstone at base of a coarsening-upward sequence within the Snakes Bight Formation at Cape Anguille........................ 22

Plate 3: Thick bedded, massive sandstones (lithofacies C) forming top of coarsening-upward sequence in the Snakes Bight Formation at Cape Anguille.............................. 22

Plate 4: Dolomite beds and laminae in black mudstones (lithofacies A) from the top of the Snakes Bight Formation near Cape Anguille lighthouse.................................... 23

Plate 5: Siltstone-shale beds of lithofacies B, Snakes Bight Formation.. 24

Plate 6: Lithofacies E intraformational mixtite.................. 28

Plate 7: Large fragment of laminated mudstone and dolomite (lithofacies A) in intraformational mixtite, Snakes Bight Formation.. 28

Plate 8: Flat-lying synsedimentary fold deforming sandstone bed within interbedded sandstones and shales of lithofacies B of the Snakes Bight Formation......................... 29

Plate 9: Thick, chaotic conglomerate beds at the base of the Friars Cove Formation.................................. 37

Plate 10: Intercalated sandstone and conglomerate at the base of the Friars Cove Formation............................... 41

Plate 11: A thick, lenticular conglomerate of lithofacies A, Friars Cove Formation.................................. 42

Plate 12: Normally graded conglomerate lying between sandstones of the Friars Cove Formation........................... 42

Plate 13: Inversely graded conglomerate from basal beds of the Friars Cove Formation.................................. 43

Plate 14: Graded pebbly sandstone bed, lithofacies A, Friars Cove Formation, Cape Anguille lighthouse................ 43

Plate 15: Crossbedded sandstone overlying erosively graded, massive sandstone.................................... 44

Plate 16: Pillar structures in a sandstone of lithofacies A, Friars Cove Formation, Cape Anguille lighthouse......... 44

Plate 17: Well bedded, planar stratified sandstone of lithofacies B, Friars Cove Formation................................ 46

Plate 18: Lithofacies B sandstone bed, Friars Cove Formation...... 47

Plate 19: Pebble layer lying gradationally within massive and stratified, very coarse and gritty sandstones........... 47

Plate 20: Interference and straight ripple-marks in thin bedded, rippled sandstones.................................. 49

Plate 21: Yellow weathering dolostones covering rippled sandstone bed, Codroy Island.................................... 50

Plate 22: Burrows and chevron trails.............................. 51

Plate: 23: Close-up of chevron trail............................... 51

Plate 24: Conglomerate composed mostly of small feldspar and ferruginous pebbles.................................... 54

Plate 25: Laminated dolomite overlying calcareous mudstone with small algal 'biscuit' near base......................... 55

Plate 26: Photomicrograph of lithofacies F, Friars Cove Formation containing dolomite-coated sand grains and some carbonate grains set in a spar cement............................ 56

Plate 27: Photomicrograph of ooids, carbonate intraclasts and silt grains set in sparry cement............................ 56

Plate 28: Cliffs on the north side of Hynes Cove showing the characteristic sheet-like geometry of the red and grayish red sandstones of the Spout Falls Formation..... 62

Plate 29: Planar stratified, gray sandstones of lithofacies B, Spout Falls Formation................................. 66

Plate 30: Very large scale, planar crossbeds overlain by co-sets of large scale, trough-crossbeds....................... 67

Plate 31: Large, low amplitude ripple marks formed by segregation of coarse and fine carbonate grains in lithofacies A of the Ship Cove Formation, Ship Cove..................... 91

Plate 32: Photomicrograph of oncolitic pellet packstone........... 92

Plate 33: Clear microspar replacing spherical nonskeletal (possibly pellet) grains in wackestone................. 92

Plate 34: Lithofacies B laminites of the Ship Cove Formation at K-295.. 93

Plate 35: Type 1 laminite, lithofacies B of the Ship Cove Formation.. 94

Plate 36: Silty laminite of lithofacies B of the Ship Cove Formation.. 95

Plate 37: Fracture in silty laminite of lithofacies B, Ship Cove Formation.. 95

Plate 38: Type 3, carbonate-fenestral laminite of lithofacies B, Ship Cove Formation.. 96

Plate 39: Oolite grains visible in a fenestra-rich laminite....... 96

Plate 40: Spherical algal structures in the Ship Cove Formation, Codroy Island.. 97

Plate 41: Highly deformed laminated limestones of the Ship Cove Formation, Codroy Island.. 97

Plate 42: Very large diameter algal structure on bedding plane in laminite of the Ship Cove Formation.................... 99

Plate 43: Facies D, limestone breccia overlying interbedded sandstone and laminite, Ship Cove Formation................ 100

Plate 44: Stratified sandstone with some laminite lithoclasts lying in channel eroded in laminite.................... 102

Plate 45: Bedded gypsum of the Codroy Road Formation, Flat Bay gypsum mine.. 110

Plate 46: Thick layer of "Ship Cove Formation - type" laminite set between two thick beds of white gypsum............. 110

Plate 47: Nodular to contorted bedded gypsum with dolomite streaks interbedded with thin bedded, deformed argillaceous dolomite.. 111

Plate 48: Gypsum laminites of the Codroy Road Formation........... 112

Plate 49: Large, white gypsum nodule and local layers of enterolithically folded laminae in gypsum laminite...... 112

Plate 50: The top of the Black Point limestone, Codroy Road Formation, Black Point, Codroy coast.................... 114

Plate 51: Photomicrograph of dolomite microspar from the Black Point limestone.. 115

Plate 52 and 53: Photomicrographs of black, argillaceous, fossiliferous dolomite 116

Plate 54: Internally structureless, stromatolite heads, (thrombolites) overlying dark gray calcareous mudstones below skeletal bioherm of the Cormorant limestone 116

Plates 55 and 56: Photomicrographs of the outer zone of the North Branch bioherm, Codroy Road Formation 117

Plate 57: Thick red siltstone unit separating two lithofacies D sandstones in the Highlands Member 129

Plate 58: Thick red siltstones intercalated with sheet sandstones of lithofacies B, Jeffrey's Village Member 129

Plate 59: Sheets and lens of fine sandstone (lithofacies B) interbedded with lithofacies A siltstones in Jeffrey's Village Member 131

Plate 60: Fine sandstones of lithofacies B, Jeffrey's Village Member 131

Plate 61: Planar stratified, gray, micaceous, fine sandstones of lithofacies C, Mollichignick Member 133

Plate 62: Tubular bioturbation in the top of reddish gray sandstone of lithofacies C, in the Mollichignick Member. 133

Plate 63: Multistory channel sandstones, lithofacies D, Jeffrey's Village Member 135

Plate 64: Thick sandstone with pebble layers and large scale trough-crossbedding 136

Plate 65: Conglomerate with crude stratification that cuts into crudely stratified, pebbly sandstone 139

Plate 66: Large trough-crossbedding in arkosic sandstones of the Overfall Brook Member 141

Plate 67: Trough-crossbedding between planar thin stratification in red, muddy sandstones of the Overfalls Brook Member.. 141

Plate 68: Bar-shaped deposit of crossbedded gritty sandstone, associated with pebbly sandstones 142

Plate 69: Two beds of caliche in red siltstones of the Mollichignick Member 146

Plate 70: Caliche cementing a conglomerate bed in the lower part of the Flat Bay section of the Jeffrey's Village Member. 147

Plate 71: Thick, nodular caliche with laminar top and remnants of red siltstone in Mollichignick Member.................. 147

Plate 72: Intraformational conglomerate lithofacies G, Highlands Member.. 148

Plate 73: Vertical cylindroids or pipes of caliche................ 148

Plate 74: Purple-gray and red caliche bed splitting a pebbly sandstone bed in two.................................... 149

Plate 75: Photomicrograph of a cemented siltstone bed from the Mollichignick Member................................. 150

Plate 76: Photomicrograph of an old caliche, Mollichignick Member.. 150

Plate 77: Bed of siliceous caliche in the Mollichignick Member.... 151

Plate 78: Interbedded calcareous mudstones and carbonates of lithofacies I, Mollichignick Member.................... 155

Plate 79: Small concretionary carbonate in calcareous mudstones of lithofacies I, Mollignick Member.................... 155

Plate 80: Photomicrograph of nodular carbonate from paludal mudstones.. 157

Plate 81: Planar, thinly stratified, micaceous, gray, very fine sandstones with local convolution and some crossbeds, lithofacies I, Mollichignick Member.................... 157

Plate 82: Red shaly siltstone of lithofacies K................... 159

Plate 83: General view of lithofacies L, Mollichignick Member..... 162

Plate 84: Laminated sandstones of lithofacies L, Mollichignick Member.. 162

Plate 85: Close-up of gray calcareous shaly mudstone overlain by stratified, dolomitic, skeletal packstone and wackestone... 163

Plate 86: Thick sequence of lithofacies M in the Jeffrey's coastal section of the Jeffrey's Village Member......... 167

Plate 87: Thick sequence of gray to black shales, sandstones and some carbonates of lithofacies M, Mollichignick Member.. 167

Plate 88: U-shaped burrows and fine tubular burrows (upper part of bed) in well sorted, laminated and bedded white quartzose sandstones of lithofacies M, Mollichignick Member.. 168

Plate 89: Thick, planar stratified sandstone interlayered with mudcracked thin mudstone layers of lithofacies M, Jeffrey's Village Member.................................. 169

Plate 90: Varicolored mudstones of lithofacies N.................. 172

Plate 91: Bedded, halite-bearing muddy siltstones of lithofacies O.. 173

Plate 92: Brown, ripple cross-laminated, very fine sandstone overlying halitic, red siltstone in sequence of lithofacies O.. 174

Plate 93: Thick, crossbedded, green-gray, very fine to fine grained sandstones of lithofacies Q..................... 176

Plate 94: Fischells limestone.................................. 179

Plate 95: The Crabbes limestone................................ 180

Plate 96: Large burrows, in dolomitic wackestone that is rich in skeletal remains, Fischells limestone.................. 182

Plate 97: Chondrites in dolomitic lime mudstone 183

Plate 98: Crinoidal wackestone composed of complete and fragmented crinoid ossicles, Crabbes limestone..................... 183

Plate 99: Skeletal-peloid packstone composed of foraminifera, crinoid ossicles, ostracods and calcispheres............ 183

Plates 100 to 101: Photomicrographs of areas of a goniatite shell enclosed in a carbonaceous dolomitic wackestone, the "round valley," Codroy lowlands................................. 184

Plate 102: Heatherton limestone, Jeffrey's Village Member, Fischells Brook.. 185

Plate 103: Heatherton limestone, Jeffrey's Village Member at Rattling Brook.. 185

Plate 104: Inclined, curved, columnar stromatolites of the Jeffrey's Village Member............................... 187

Plate 105: Close-up of columnar stromatolites on Highlands River... 187

Plate 106: Lumpy, black algal carbonate of lithofacies R, Jeffrey's Village Member.. 188

Plate 107: Photomicrograph of small clots of codiacean algae that form lumpy algal carbonates at Rattling Brook........... 189

Plate 108: Worm tubes lined by fine acicular druse and by mosaic spar.. 190

Plate 109: Oolitic limestone in carbonate unit at base of Flat Bay section, Jeffrey's Village Member 191

Plate 110: Oolitic grainstone from unit in Flat Bay 191

Plate 111: Close-up of radial ooids from oolitic grainstone 192

Plate 112: Coated sand grains in a calcareous, very fine sandstone from carbonate unit, Jeffrey's Village Member 192

Plate 113: Red, laminar calcrete surrounding coarse fenestral core in calcrete-modified algal heads of the Heatherton limestone 194

Plate 114: Nodular calcrete capping a fossiliferous limestone and calcareous sandstone of the Jeffrey's Village Member on the North Branch River 194

Plate 115: Interbedded limestone-breccias (lithofacies R) with beds of red siltstones above main 'Codroy Breccia' 197

Plate 116: Close-up of limestone-breccia of the 'Codroy Breccia,' Jeffrey's Village Member 197

Plates 117 to 122: Photomicrographs of selected lithoclasts of the 'Codroy Breccia' 198

Plate 123: Layered white and red gypsum, rich in gypsum porphyroblasts, lithofacies S, Jeffrey's Village Member 200

Plate 124: Close-up of radiating, chevron-like structure in gypsum 200

Plate 125: Black shale with limestone laminae, beds and concretions (lithofacies A), base of type section of Woody Cape Formation 222

Plate 126: Shale and shaly mudstone intercalated with black lumpy dolomite and limy dolomites, lithofacies A, Woody Cape Formation 222

Plate 127: Coarsening-upward sequence of sheet-like deposits of mudstone, siltstone and silty sandstone, lithofacies D and E, Woody Cape Formation 225

Plate 128: Interbedded siltstones and mudstones of lithofacies D, Woody Cape Formation, Capelin Cove 225

Plate 129: Ripple cross-laminated, sandy siltstone gradationally overlying cross-laminated silty mudstone of lithofacies D, Woody Cape Formation 227

Plate 130: Composite unit of sandstone with sheeted geometry, lithofacies E, Woody Cape Formation 227

Plate 131: Crinoid and ostracod fragments and a whole brachiopod in skeletal wackestone, lithofacies H, Woody Cape Formation, Capelin Cove.................................. 231

Plate 132: Photomicrograph of calcarenite of lithofacies H, Woody Cape Formation.. 232

Plate 133: Fining-upward sequences consisting of gray sandstones (lithofacies A) overlain by red siltstones (lithofacies B) in the Searston Formation type section............... 250

Plate 134: Thick gray sandstone (lithofacies A) in the Searston Formation at Northwest Cove............................. 255

Plate 135: Crossbedded grit lying just above base of thick channel sandstone unit, lithofacies A, Searston Formation in Northwest Cove... 255

Plate 136: Large "chute?" channel that cuts through ripple cross-laminated, micaceous, gray, fine grained sandstone...... 257

Plate 137: Trace fossils on a slab of lithofacies A, gray sandstone at top of thick channel sandstone unit.................. 257

Plate 138: Lithofacies B and C in the Searston Formation at Northwest Cove... 259

Plates 139 to 140: Sandstones and gray shales of lithofacies D, Searston Formation... 261

Plate 141: Unbedded conglomerates of lithofacies F, Searston Formation... 262

Plate 142: Close-up of subrounded pebbles in the basal conglomerate at Trainvain Brook.................................. 263

Plate 143: Thick crude bedding and lenses of pebbly sandstone in conglomerate of lithofacies F, Searston Formation....... 264

Plate 144: Thick conglomerate beds with lenses of brown, thin bedded sandstones...................................... 264

Plate 145: Brown, muddy sandstones displaying planar thin stratification with pebble layers............................. 266

Plate 146: Crossbeds and spherical concretions in brown-red sandstone... 266

ABSTRACT

The Bay St. George subbasin is one of two major depressions filled by Carboniferous sediments in insular Newfoundland. It is the northeast extension of the larger Maritimes Basin and contains approximately 10 km of sediments ranging in age from Late Devonian to Late Carboniferous. The strata are divided into three groups: the Anguille Group (Famennian - Tournaisian age), Codroy Group (Viséan age) and Barachois Group (Namurian-Westphalian age). All three groups are mostly nonmarine terrigenous clastic sediments with marine strata only within the Codroy Group.

The subbasin formed as a pull-apart trough adjacent to, and west of, the northeasterly trending Long Range fault, a major strike-slip structure that is part of the Hercynian Cabot Fault system in western Newfoundland. Dextral, strike-slip movements began in Middle or Late Devonian time and ended in Early Carboniferous (middle Viséan) time. Three basin-fills, each approximately 3000 m thick, filled the initial pull-apart sequentially from southwest to northeast. The first two basin-fills of Famennian and Tournasian age (Anguille Group), were deposited within an elongate, 30 km wide trough which initially formed between divergent faults near the southern margin of the Precambrian Steel Mountain anorthosite and which with time enlarged southwestward. The third basin-fill is made up of middle Viséan strata (basal part of the Codroy Group). By this time, the subbasin had broadened to 60 km, and was irregular in shape, consisting of several subsiding depressions separated by fault-bounded archs. Wrench movements ceased in middle Viséan time and the subbasin was subsequently influenced by block faulting until the Westphalian. During this final period, sediments of the upper part of the Codroy Group and of the Barachois Group were deposited.

The Anguille Group comprises Famennian redbeds (Kennels Brook Formation), and Tournaisian deepwater lacustrine black shales, mudstones, and turbidite and deltaic sandstones (Snakes Bight Formation), gray fluvial-deltaic sandstones and shales (Friars Cove Formation), and red braided stream sediments (Spout Falls Formation). Gray conglomerates of the Fischells conglomerate member of the Spout Falls Formation formed a local alluvial fan on the northwestern margin of the subbasin.

The Codroy Group of middle to late Viséan age consists of marine and nonmarine rocks that appear to overlie conformably the Anguille Group. The basal Ship Cove Formation is a thin, subtidal to intertidal, laminated limestone (Windsor subzone A). Subsequent marine sedimentation includes sulphate and chloride evaporites that accumulated in sabkhas and shallow salinas (Codroy Road Formation and lower Jeffrey's Village Member of the Robinsons River Formation - Windsor subzones A and lower B). Associated carbonates and fine grained gray to red siliciclastic rocks of the Codroy Road Formation and Jeffrey's Village Member formed in shallow seas, in lagoons, on shorelines and rarely as bioherms. Some nonmarine redbeds are intercalated with the basal marine deposits, and increasingly dominate the upper part of the Jeffrey's Village Member and the overlying Highlands Member of the Robinsons River Formation (Windsor subzones B and C). These redbeds were laid down on playa flats, on coastal and alluvial plains and on alluvial fans. Younger strata of the Codroy Group are confined to the southwest of the subbasin. Floodplain and alluvial fan sediments were deposited there, together with minor lacustrine and shallow marine rocks of the Mollichignick and Overfall Brook Members of the Robinsons River Formation, and deltaic rocks of the Woody Cape Formation (Windsor subzones D and E).

The Upper Carboniferous Barachois Group probably overlies conformably the Codroy Group although contacts are now faulted. It consists of fluvial sandstones and siltstones laid down by high-sinuosity rivers that flowed westward across a floodplain. Minor coal measures accumulated in limnic settings on this floodplain during Westphalian time.

Detritus for all three groups was principally derived from uplifted Lower Paleozoic crystalline and volcanic terranes southeast and northeast of the subbasin. Lower Paleozoic platformal carbonates and quartzites and allochthonous Taconic ophiolite and flysch sequences were an important local source area for the Anguille Group northwest of the subbasin.

Evaporites and calcretes suggest that the Carboniferous climate was dominantly semiarid. Aridity was most intense during the middle Viséan and humidity greatest during the late Viséan and the Westphalian.

The subbasin was deformed in the Late Carboniferous. Major northeasterly trending folds that strike obliquely to the Long Range fault and northeasterly trending synthetic and northwesterly trending antithetic faults developed during renewed strike-slip faulting along the Long Range fault and associated northeasterly trending faults. The orientation and geometry of these structures suggests that right-lateral shear occurred, with a minimum lateral displacement of 10 km. Block faulting with displacements locally of thousands of metres followed.

Economic gypsum deposits, subeconomic salt and minor potassic salt prospects occur in the Codroy Group in the north of the subbasin. Minor chalcopyrite, galena, sphalerite, barite and celestite are present throughout the subbasin with the best showings consisting of barite and celestite in the basal Codroy Group along the northern margin of the subbasin. Minor uranium-copper occurrences are found in the youngest Codroy strata in the southwest of the subbasin. Several uneconomic thin coal seams occur in the Barachois Group.

CHAPTER 1

INTRODUCTION

Rocks of Carboniferous age occur in several areas of Newfoundland (Figures 1 and 2); the best known are those in the Deer Lake and St. George's Bay areas. The Carboniferous rocks of the St. George's Bay area form the northeastern corner of the Maritimes Basin (Williams, 1974), a much larger Carboniferous basin that underlies the Gulf of St. Lawrence and adjacent land areas (Figures 1 and 2). The part of the basin in southwestern Newfoundland is termed the Bay St. George subbasin and it is the subject of this report. Onshore the subbasin is developed in a zone 22 km wide between St. George's Bay and the Long Range Mountains, extending 125 km from the coast near the Codroy Valley, northeast to the vicinity of Stephenville. Rocks of Carboniferous age that belong to the Bay St. George subbasin extend offshore beneath St. George's Bay (Figure 2).

Geographical Setting

Three distinct topographic areas occur in the Bay St. George subbasin, namely, the St. George's Bay lowlands, the Anguille Mountains and Bald Mountain, and the Codroy lowlands (Figure 3).

The St. George's Bay lowlands consist of a gently rolling coastal plain, 60 m in elevation, which rises gradually to 225 to 300 m as it is traced inland towards the Long Range Mountains. The latter mountains form a dissected 450 m plateau, rising abruptly from the lowlands along a pronounced scarp. The lowlands are fashioned generally from easily weathered sedimentary rocks of the Codroy and Barachois Groups. However, more resistant strata in the vicinity of Brow Pond and Mt. Howley form a steep upland plateau, 300 to 375 m high. Thick glacial drift as well as outwash and marine deposits (Brookes, 1969, 1977b; Vanderveer, 1975) cover much of the area and have been incised up to 90 m by rivers which cross the lowlands northwestward from the Long Range Mountains.

The Anguille Mountains and Bald Mountain are composed of more resistant Anguille Group strata and form an upland, averaging 525 m in elevation with steep flanks, generally reflecting the structural dip of underlying rocks. Streams, which are generally short with a steep gradient, radiate out from the mountains, whereas some long streams run parallel to the structural trends. The mountains were only locally affected by glaciation (Twenhofel and MacClintock, 1940; Brookes, 1977a).

The Codroy lowlands are a southwesterly trending, funnel-shaped geomorphic feature beginning near South Branch and opening out to the southwest; they are drained by the Grand Codroy and Little Codroy Rivers. The lowlands are a preglacial feature, modified by Wisconsin ice movements (Brookes, 1977a) and scoured in Codroy and Barachois Group strata. They lie between the Anguille Mountains and the southern end of the Long Range Mountains.

The coastline throughout the area is lined by cliffs. Sandy beaches are rare except locally in the Codroy lowlands and more extensively along St. George's Bay. The area is generally covered with spruce forests, low-lying tuckamore spruce, open heaths and large boglands. A cool temperate climate with moderate precipitation and generally heavy snowfall is characteristic of the area. Summers had little rainfall during the period of the study.

Access to the area is provided by the Trans Canada Highway from which

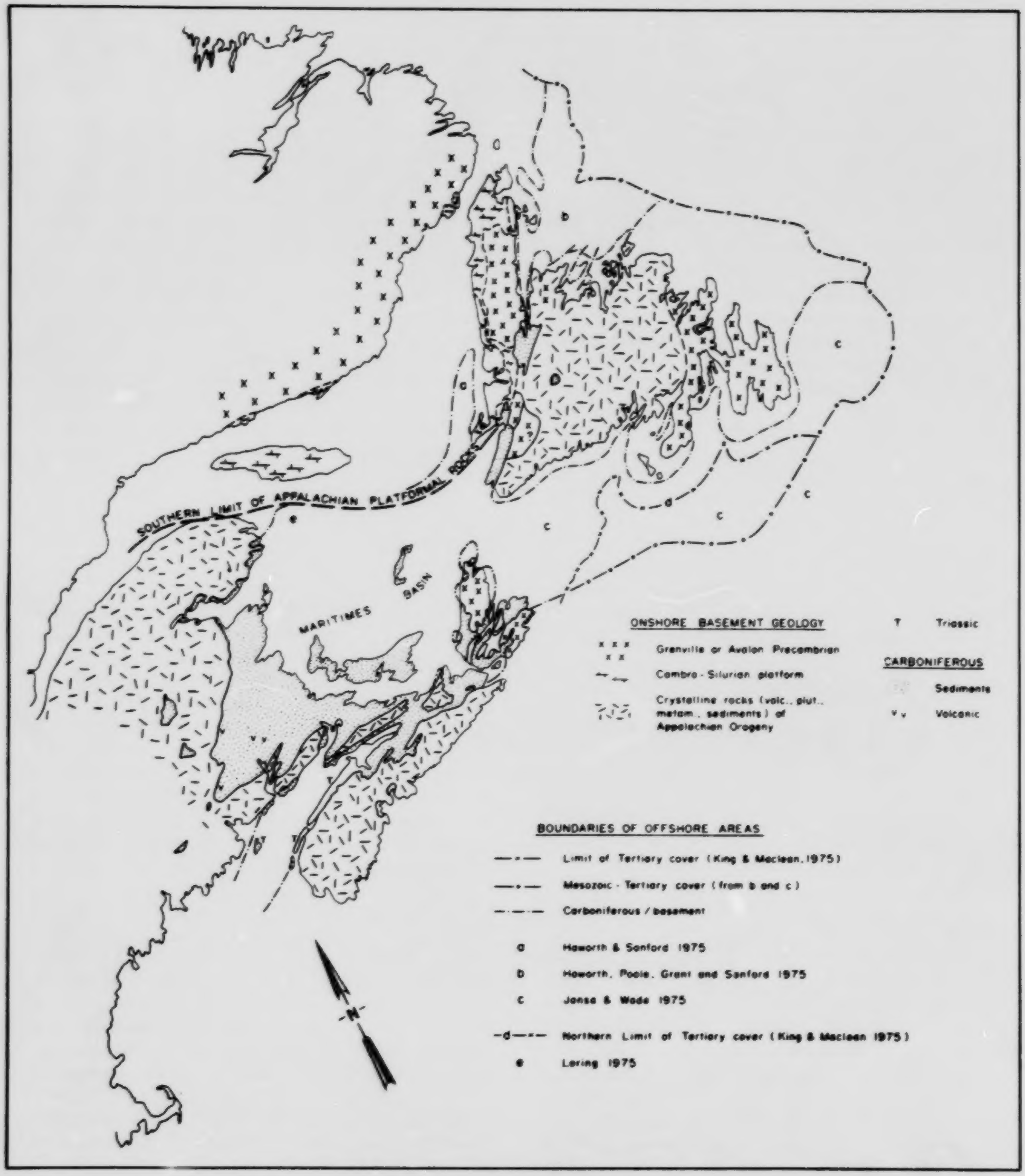

SOUTHERN LIMIT OF APPALACHIAN PLATFORMAL ROCKS
MARITIMES BASIN
a
b
c
d
e
N
ONSHORE BASEMENT GEOLOGY
Grenville or Avalon Precambrian
Cambro - Silurian platform
Crystalline rocks (volc., plut., metam., sediments) of Appalachian Orogeny
T Triassic
CARBONIFEROUS
Sediments
Volcanic
BOUNDARIES OF OFFSHORE AREAS
Limit of Tertiary cover (King & Maclean, 1975)
Mesozoic - Tertiary cover (from b and c)
Carboniferous / basement
a Haworth & Sanford 1975
b Haworth, Poole, Grant and Sanford 1975
c Jansa & Wade 1975
-d- Northern Limit of Tertiary cover (King & Maclean 1975)
e Loring 1975

Figure 1: Generalized distribution of onshore Carboniferous strata and surrounding basement rocks in Newfoundland and the Maritime Provinces. Carboniferous-basement relationship and westward limit of younger Mesozoic and Tertiary strata unconformably upon the Carboniferous shown for the offshore areas.

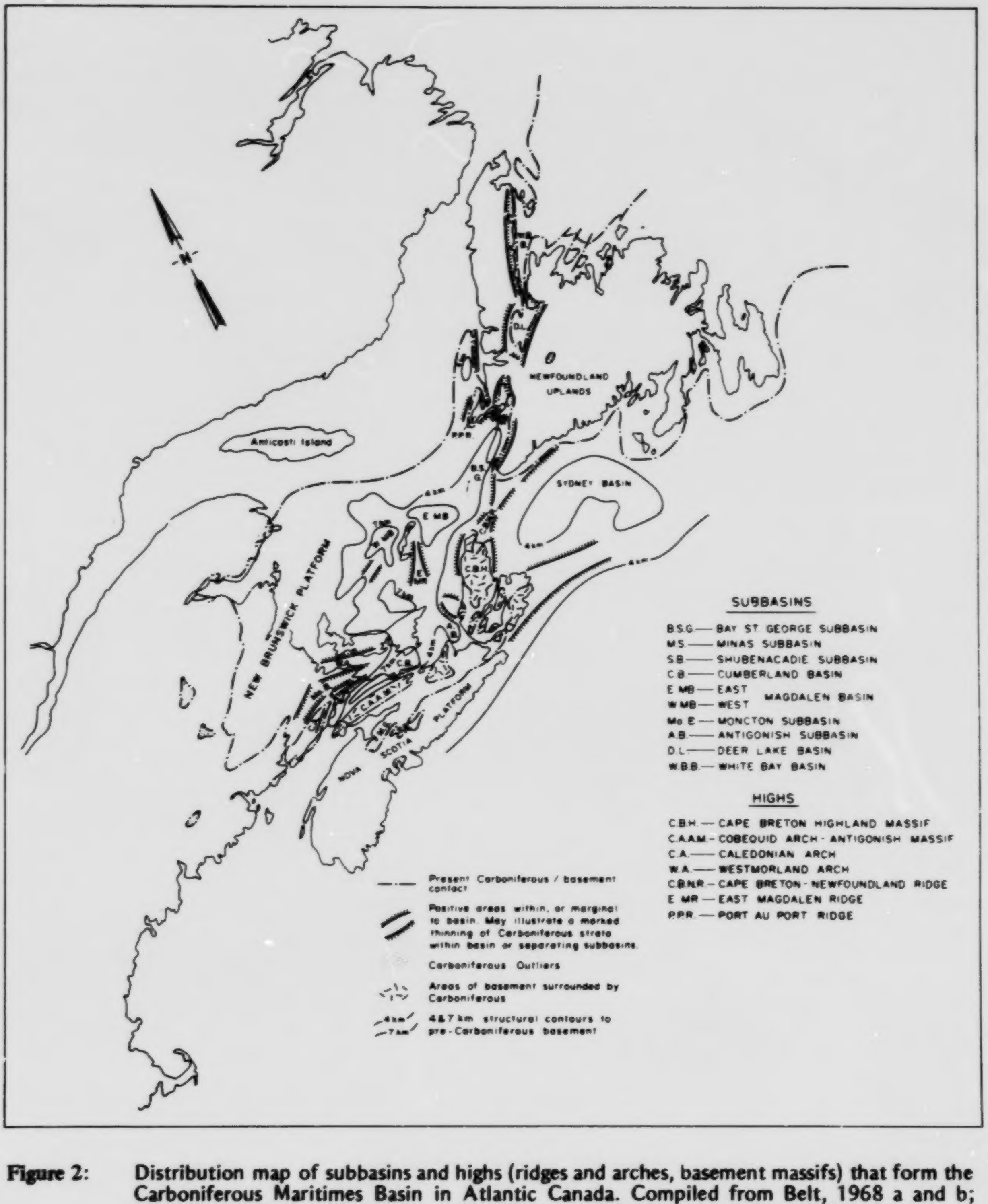

N
Anticosti Island
NEWFOUNDLAND UPLANDS
SYDNEY BASIN
P.P.R.
B.S.G.
D.L.
E MB
C.B.H.
C.A.A.M.
C.B.
NEW BRUNSWICK PLATFORM
NOVA SCOTIA PLATFORM
4 km
SUBBASINS
B.S.G. — BAY ST. GEORGE SUBBASIN
M.S. — MINAS SUBBASIN
S.B. — SHUBENACADIE SUBBASIN
C.B. — CUMBERLAND BASIN
E MB — EAST
W MB — WEST
MAGDALEN BASIN
Mo. E — MONCTON SUBBASIN
A.B. — ANTIGONISH SUBBASIN
D.L. — DEER LAKE BASIN
W.B.B. — WHITE BAY BASIN
HIGHS
C.B.H. — CAPE BRETON HIGHLAND MASSIF
C.A.A.M. — COBEQUID ARCH - ANTIGONISH MASSIF
C.A. — CALEDONIAN ARCH
W.A. — WESTMORLAND ARCH
C.B.N.R. — CAPE BRETON - NEWFOUNDLAND RIDGE
E MR — EAST MAGDALEN RIDGE
P.P.R. — PORT AU PORT RIDGE
Present Carboniferous / basement contact
Positive areas within, or marginal to basin. May illustrate a marked thinning of Carboniferous strata within basin or separating subbasins.
Carboniferous Outliers
Areas of basement surrounded by Carboniferous
4 km
7 km
4&7 km structural contours to pre-Carboniferous basement

Figure 2: Distribution map of subbasins and highs (ridges and arches, basement massifs) that form the Carboniferous Maritimes Basin in Atlantic Canada. Compiled from Belt, 1968 a and b; Sheridan and Drake, 1968; Watts, 1972; Mayhew, 1974; Howie and Barss, 1975a.

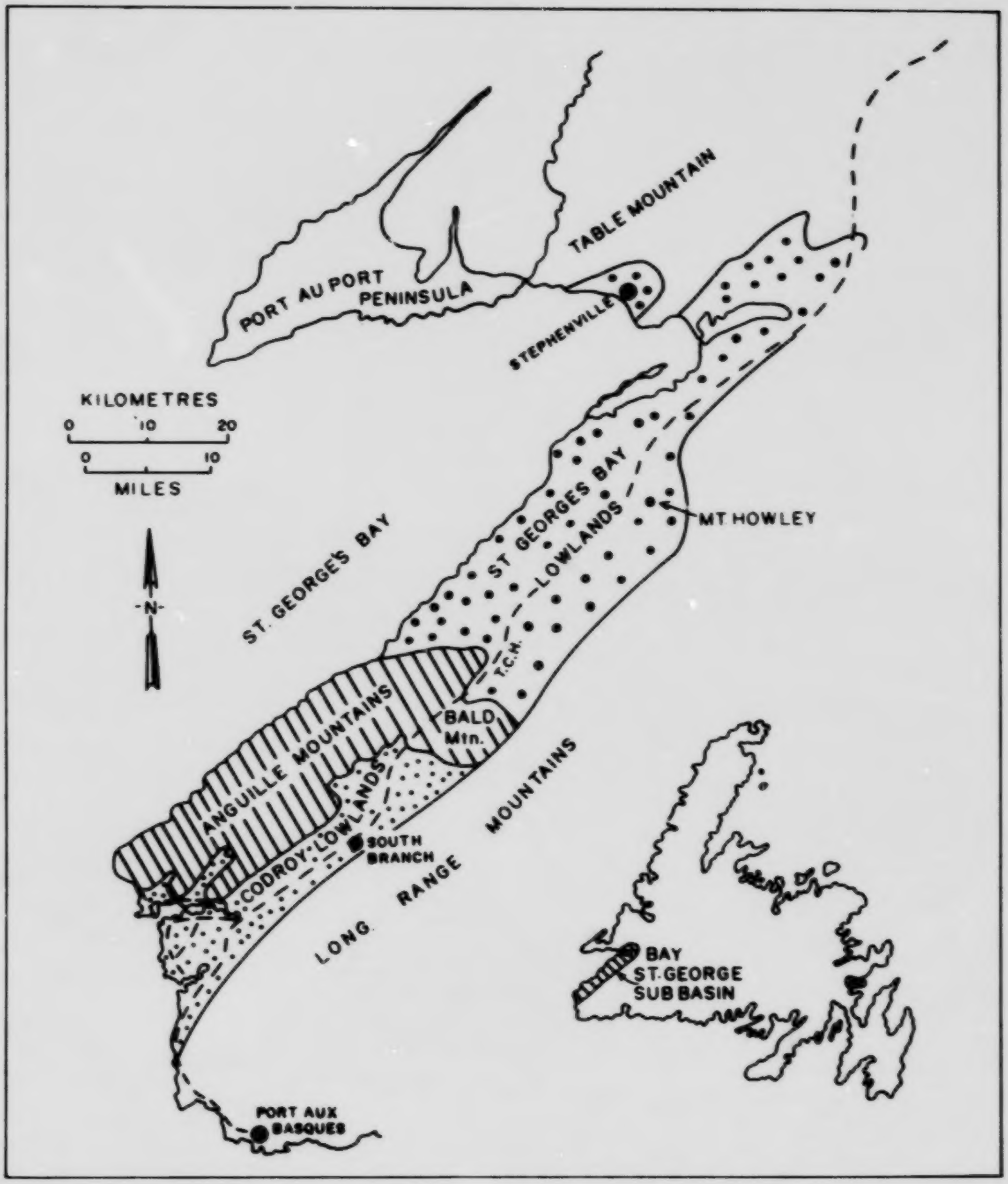

PORT AU PORT PENINSULA
TABLE MOUNTAIN
STEPHENVILLE
KILOMETRES
0 10 20
0 10
MILES
N
ST. GEORGE'S BAY
ST GEORGES BAY LOWLANDS
MT HOWLEY
T.C.H.
BALD Mtn.
ANGUILLE MOUNTAINS
CODROY LOWLANDS
SOUTH BRANCH
LONG RANGE MOUNTAINS
PORT AUX BASQUES
BAY ST.GEORGE SUB BASIN

Figure 3: Major geomorphological subdivisions of the Bay St. George subbasin.
—— highways and roads.

secondary roads branch to the many coastal settlements. Woods roads, power lines, the main Newfoundland railway line, and rivers and streams provide further access into the area. Much of the coast in the St. George's Bay and Codroy lowlands is accessible by road and foot but the coastal exposures in the Anguille Mountains generally cannot be reached without the use of a small boat.

Regional Geological Setting

Carboniferous rocks are extensive throughout the Atlantic Provinces (Poole, 1967; Belt, 1968a and b; Hacquebard, 1972) and offshore areas that surround Newfoundland (Sheridan and Drake, 1968; Watts, 1972; Williams, 1974; Haworth and Sanford, 1976; Haworth et al., 1976; Jansa and Wade, 1975) (Figure 1). A Carboniferous basin has been delineated by onshore mapping and extensive geophysical surveys of offshore areas. It underlies large parts of Nova Scotia, New Brunswick, Cape Breton and Prince Edward Island and extends beneath the Gulf of St. Lawrence to outcrop onshore in southwestern Newfoundland.

The name Maritimes Basin (Williams, 1974), is preferred here to Fundy Basin (Belt 1965, 1968a and b, 1969; Kelley, 1967b), Fundy geosyncline (Poole, 1967), Fundy epieugeosyncline (Hacquebard, 1972; Howie and Barss, 1975a and b) or St. Lawrence basin (Geldsetzer, 1979). The term Maritimes Basin is used strictly in the geographical sense to define a depositional basin in which all salient features of the Carboniferous of the area can be grouped and includes no reference to the presence or absence of deformation.

Three structural elements occur in the Maritimes Basin: platforms, subbasins and arches or ridges. The platforms (Figure 2) overlie older Acadian basement and are composed of relatively undeformed sedimentary rocks up to 2000 m thick. They include the New Brunswick platform and the Nova Scotia platform. The Newfoundland platform, which Belt (1969) and Hacquebard (1972) proposed as occurring in the central part of the Island, does not strictly conform to the above definition of a Carboniferous platform. Central Newfoundland shows no evidence of having been covered by a sedimentary blanket; instead, during the Carboniferous, it was a major upland from which large quantities of detritus were shed into the adjacent basins. Some fault-controlled Carboniferous deposits were, however, laid down in very localized, landlocked valleys, e.g. Red Indian Lake (Kean, 1978).

A complex of subbasins containing up to 9 km depth of Carboniferous rocks (Figure 2) occurs in the centre and along the southeastern side of the Maritimes Basin. They have been delineated by mapping, geophysical surveys and drilling, and include the Cumberland basin, Moncton basin and East and West Magdalen basins (Belt, 1968b; Watts, 1972). The Bay St. George subbasin projects northeastwards from the East Magdalen basin (Haworth, 1975a and b) from which it is separated by a narrow arch (Howie and Barss, 1975a). Hobson and Overton (1973) and Spector (1969) suggested that 6 km depth of sedimentary rocks occur in the Bay St. George subbasin; however, the present work suggests that up to 10 km of sediment was originally deposited. A small, unnamed, north trending Carboniferous subbasin formed along the western edge of the Humber Arm Allochthon just west and north of the Port au Port Peninsula (Shearer, 1973; Haworth and Sanford, 1976).

The subbasins are separated by ridges or arches (Figure 2). These topographic highs are composed of exposed basement rocks such as the Cape Breton Highland Massif and Cobequid Arch - Antigonish Massif (Belt, 1968b), or are covered by thinned Carboniferous sedimentary rocks up to 4 km thick, for example, the East Magdalen Ridge (Watts, 1972; Mayhew, 1974). A major ridge, the Cape Breton - Newfoundland Ridge (Watts, 1972; Mayhew, 1974), extends across Cabot Strait from the Cape Breton Highland Massif to the Long Range Mountains of southwestern Newfoundland. This ridge forms part of the southeastern margin of the Maritimes Basin, separating it from the Sydney Basin (Howie and Barss, 1975a and b; Jansa and Wade, 1975) and other depocenters on the Grand Banks and the continental shelf of Atlantic Canada. Howie and Barss (1975a) believe, however, that a thin veneer of Carboniferous rocks was probably deposited over the Cape Breton - Newfoundland ridge. The Deer Lake and White Bay Carboniferous basins, although only 50 km northeast of the Bay St. George subbasin, are believed to have been separated by an upland that supplied detritus to both basins.

The Maritimes Basin is essentially a successor basin formed after the completion of the Acadian deformation of the Appalachian fold belt (Poole, 1967; Belt, 1968b; Hacquebard, 1972; Williams et al., 1974). Uplift of the fold belt probably started during or soon after the Early Devonian, and molasse sedimentation became widespread by the Late Devonian in a taphrogenic zone (Poole, 1976). The northern margin of the Maritimes Basin probably lies along the southern edge of the Laurentian platform northwest of the Appalachian Orogen. It coincides with the northern limit of Acadian deformation (Haworth, 1975a and b), which generally trends westward from the Port au Port Peninsula to the south of Anticosti Island.

The Maritimes Basin was filled mainly by fluviatile sediment throughout its history, beginning in Late Devonian time and continuing to the Early Permian (Geldsetzer, 1978; Hacquebard, 1972). Lacustrine sedimentary rocks (Belt, 1965, 1968a) also occur, and one major marine incursion is recorded in Upper Mississippian strata (Bell, 1929; Mamet, 1970). Several rock groups are defined in the Maritimes Basin, namely, in ascending order, the Horton, Windsor, Canso/Riversdale, Cumberland and Pictou Groups (Hacquebard, 1972). In southwestern Newfoundland three groups have been defined, namely, the Anguille, Codroy and Barachois Groups. They are broadly both lithological and time equivalents of the Horton, Windsor, Canso/ Riversdale and, possibly, Cumberland Groups of Nova Scotia (Table 1). The main marine incursion is recorded in the Windsor-Codroy Groups. It corresponds to a late Viséan marine transgression which occurred throughout North Africa and Europe (Schenk, 1971; Dillon and Sougy, 1974). A major hiatus in sedimentation from late Tournaisian until middle Viséan time has been postulated to have occurred in the Maritimes Basin before deposition of the marine sequence (Geldsetzer, 1977, 1978; Mamet, 1970; Utting, 1980). This is disputed, however, by Belt (1968a and b), Schenk (1975a) and Howie and Barss (1975a), who found no sedimentary break in many places. Recent spore studies reveal a mixed Horton-Windsor assemblage in basal Windsor units which Utting (1980) hinted may support the view that the two groups are conformable. Rock-stratigraphic relationships in the Bay St. George subbasin support the notion of a conformable boundary. Here, as elsewhere in Maritime Canada, no biostratigraphic evidence is available to augment the lithostratigraphic relationships.

In general, volcanic rocks are rare in the Maritimes Basin. They do, however, occur in the Mississippian and Pennsylvanian of New Brunswick and the Magdalen Islands, in Hortonian strata of the Fisset Brook Formation on Cape Breton, and in Upper Devonian rocks near Antigonish (Keppie et al., 1978). The Fisset Brook Formation abuts the Cape Breton Highland Massif (Figure 2) and is considered to underlie and to be older than strata of the Horton Group. It consists of intermediate to felsic volcanic rocks intercalated with Horton-type sedimentary rocks (Kelley and Mackasey, 1965). They compare closely in

Table 1: Stratigraphic nomenclature used by present and previous workers for rock units in the Bay St. George Subbasin.

										STAGES		
Murray (1873)	Hayes and Johnson (1938)	Bell (1948)	Baird (1959)		Baird and Cote (1964)	Utting (1966)	Knight, this report			NOVA SCOTIA	EUROPE	NORTH AMER.
			Codroy Section	Ship Cove-Fischells Section			Codroy lowlands - Anguille Mountains		St. George's Bay lowlands			
COAL MEASURES OR PENNSYLVANIAN	BARACHOIS SERIES	BARACHOIS SERIES	BARACHOIS SERIES	BARACHOIS SERIES	BARACHOIS GROUP	BARACHOIS GROUP	BARACHOIS GROUP		BARACHOIS GROUP	PICTOU	WESTPHALIAN C	PENNSYLVANIAN
										CUMBERLAND	B	
Div. E Green and red sandstone, brown and black shale, coal beds with underclays							upper coal-bearing sequence		"undivided"	RIVERSDALIAN	A	
Div. D Brown and red sandstone, conglomerate; brown, black, and green micaceous shale, plant fossils		Searston Beds	Searston Beds	Searston Beds	including Searston Beds	Searston Beds	Searston Formation			CANSOAN	NAMURIAN	
WINDSOR MARINE SERIES	CODROY SERIES	CODROY SERIES	CODROY SERIES	CODROY SERIES	CODROY GROUP		CODROY GROUP		CODROY GROUP	WINDSOR	VISEAN	MISSISSIPPIAN
								Robinsons River Fm	Robinsons River Fm			
Div. C Variegated red, green and dark marls with Windsor marine fauna, sandstone	Woody Point sandstone	Woody Head beds	Woody Point beds	Highlands sandstone				Overfall Brook Member				
					UPPER		Woody Cape Formation	Mollichignick Member	Brow Pond Lentil			
	Woody Point shales and limestone	Woody Cove beds	Woody Cove beds	Crabbs and Jeffrey's limestone and interbedded sandstones and siltstones					Highlands Member			
		Crabbs and Jeffrey's limestone						Jeffrey's Village Member	Jeffrey's Village Member			
Div. B Gypsum, green, red and brown shales, black and dark gray limestone	Black Point limestone, Codroy shales and gypsum	Black Point limestone Gypsiferous Zone	Codroy beds including the Black Point limestone	Codroy beds including Heatherton, Fischells, Cormorant limestones	LOWER		Codroy Road Formation		Codroy Road Formation			
		Ship Cove limestone	Ship Cove limestone	Ship Cove limestone			Ship Cove Formation		Ship Cove Formation			
Div. A	ANGUILLE SERIES	ANGUILLE SERIES	ANGUILLE SERIES	ANGUILLE SERIES	ANGUILLE GROUP		ANGUILLE GROUP		ANGUILLE GROUP	HORTON	TOURNAISIAN	
Conglomerate plus flaggy sandstone and greenish shales	Snakes Bight shale, Cape Anguille sandstone		Seacliffs sandstone	Fischells conglomerate Seacliffs sandstone	Seacliffs Formation		Spout Falls Formation		Fischells conglomerate member (Spout Falls Formation)			
							Friars Cove Formation					
			Snakes Bight shale	Snakes Bight shale	Snakes Bight Formation		Snakes Bight Formation					
			Anguille sandstones	Anguille sandstones	Cape John Formation		Kennels Brook Formation			PRE-HORTON	FAMENNIAN	DEVONIAN

tectonic position and lithology to the Windsor Point Group (Brown, 1977; Chorlton, 1979; Chorlton and Dingwell, 1981) which lies along the Cape Ray Fault in southwestern Newfoundland. However, sedimentary rocks from the Windsor Point Group (Chorlton, 1979; Chorlton and Dingwell, 1981; Cooper, 1954) contain plant fossils which have been dated as Early Devonian (Dorf and Cooper, 1943; Chorlton, personal communication, 1980) and hence are clearly older than the Fisset Brook Formation of Cape Breton.

The rocks of the Maritimes Basin were deformed in the Late Carboniferous during the Maritime disturbance (Poole, 1967, 1976; Schenk, 1971, 1978). The deformation was most intense along a narrow zone which extends through the Deer Lake Basin (Hyde, 1978, 1979a, and b; Hyde and Ware, 1980) to the Bay St. George subbasin and across the Cabot Strait to the western side of Cape Breton. It then passes westwards through northern Nova Scotia and southwestwards into southern New Brunswick. This structural zone is called the Fundy 'basin' by Belt (1968a and b). Deformation in the zone produced *en echelon* fold axes, recumbent folds, cleavage, steep to inverted bedding and high angle, marginal and in-basin faults. For these and other reasons, Belt (1968b, 1969) related the deformation to oblique-slip movements along the basin margin faults. Tilted Lower Carboniferous rock sequences are overlain unconformably by younger Carboniferous strata in the Deer Lake Basin (Hyde and Ware, 1981), in Northern Cape Breton (Currie, 1977) and at Cape George, northern Nova Scotia (Keppie et al., 1978). Such occurrences testify to local uplift and deformation adjacent to faults during various time intervals in the axial mobile zone of the Maritimes Basin.

Paleo-reconstructions of Laurussia and Gondwanaland (LeFort and van der Voo, 1981) at the end of the Carboniferous, and detailed studies of Devonian and Carboniferous rock facies and deformational events in North America, North Africa and Europe (Schenk, 1971; McKerrow and Zeigler, 1972; Rast and Grant, 1973; Dewey, 1974; Dewey and Kidd, 1974) indicate that the Late Carboniferous - Early Permian Variscan/Hercynian orogeny must have affected the Maritimes area. The deformation is postulated to have resulted from collision of the North African plate with the North American plate. In Atlantic Canada it produced the Maritime disturbance (Dewey and Kidd, 1974) which was confined to the mobile zone of the Maritimes Basin. Zones of deformation coincide with areas of thickest Carboniferous deposition. More recently, paleomagnetic and paleotectonic analysis of Devonian and Carboniferous strata on a global scale suggest that both sedimentation and deformation were controlled by large scale, wrench fault movements (Schenk, 1978; Kent and Opdyke, 1978, 1979; van der Voo et al., 1979; Irving, 1979; Bradley, 1982).

Devonian and Carboniferous paleomagnetic poles for the Maritimes Basin differ from those of cratonic North America (Kent and Opdyke, 1978, 1979; Irving, 1979). This has led these authors to suggest major left-lateral displacement by 1500 km of an exotic terrane called Acadia (Kent and Opdyke, 1979) or Appalachia (Irving, 1979). The movements, which are postulated to have continued from the Devonian to the Permian, would clearly have influenced the siting and/or migration of basins as well as their infill and their deformation throughout the Middle and Late Paleozoic.

In contrast, the formation of the Variscan fold belt has recently been reinterpreted as the product of a right-lateral megashear between a sutured American-European plate and an African plate (Arthaud and Matte, 1977). Maritime Canada, in its position close to the southern margin of the American-European plate, is shown to be part of this system (Figure 9, page 1317, Arthaud and Matte, 1977). Bradley (1982) recently interpreted the formation and deformation of the Maritimes Basin as the products of dominantly right-lateral strike slip upon major regional faults.

Stratigraphic, sedimentologic and structural relationships within the Carboniferous rocks in the Bay St. George subbasin all suggest its evolution was largely influenced by right-lateral wrench tectonics and by block faulting. Preliminary petrographic studies also indicate that the basin evolved adjacent to the geologic terranes that presently surround it.

Local Geological Setting

The northeasterly trending Bay St. George subbasin is located at the junction of the southern margin of the St. Lawrence platform and the Acadian-deformed rocks of central Newfoundland. It is closely associated both geographically and depositionally with a major fault zone that includes the Cabot Fault of Wilson (1962) to the north of the subbasin and the Long Range fault (Bell, 1948; Riley, 1962), which forms the southeastern margin of the subbasin itself.

Two distinct basement terranes occur to the north and southeast of the Bay St. George subbasin. To the north, the basement is composed of rocks which together form the Humber tectonostratigraphic zone of the Newfoundland Appalachians (Williams, 1978). The rock types (Williams et al., 1972, 1974) include (1) Precambrian gneisses, probable Grenvillian granites and anorthosites and Cambrian diabase dikes; (2) Cambro-Ordovician clastic and carbonate rocks; (3) transported sedimentary, volcanic and ophiolitic rocks of the Humber Arm Allochthon; (4) greenschist-grade metasedimentary rocks similar to the Fleur de Lys Group; and (5) late Silurian - Devonian redbeds of the Clam Bank Formation (Rodgers, 1965; O'Brien, 1975).

To the southeast, the basement formed a major upland area in central Newfoundland. This upland was surrounded by Devonian and Carboniferous molasse and is now underlain by rocks of Precambrian(?) to Devonian age. It includes dismembered ophiolites, metamorphic, volcanic, sedimentary and intrusive rocks of the Dunnage and Gander Zones of Williams (1978). The southern part of the Long Range Mountains which lie adjacent to the Bay St. George subbasin were included in the Humber Zone by Williams (1978). New evidence (Chorlton and Dingwell, 1981; Chorlton *in* Chorlton and Knight, in press) indicates, however, that a large part of this area is underlain by Lower Palaeozoic oceanic crust and should be assigned to Williams' Dunnage Zone.

The geologic terrane southeast of the Long Range fault is traversed by the Cape Ray fault. The latter separates deformed Lower Paleozoic oceanic crust (Long Range tonalitic gneisses and rocks of the Long Range ultramafic-mafic complex of Brown, 1976) from a thick succession of Ordovician metasedimentary and island arc volcanic-sedimentary rocks that overlie amphibolitized oceanic crust (Bay du Nord and La Poile Groups) (Chorlton *in* Chorlton and Knight, in press). Granitoids are present on both sides of the Cape Ray fault. The Devonian Windsor Point Group is composed of a strongly bimodal, subaerial volcanic rock suite with interbedded volcaniclastic and sedimentary rocks and occurs at several localities along the trace of the fault.

Ordovician to Silurian felsic to mafic lavas, pyroclastics and related volcanogenic sediments of the Victoria Lake and Buchans Groups (Kean, 1977, 1978) occur further north in the central Newfoundland upland. These grade southwards into a belt of paragneiss and migmatites (Jayasinghe, 1979). Red beds and intercalated, subaerial, mafic to felsic volcanic rocks of the Botwood and Springdale Groups (Williams et al., 1972; Kean, 1979) are also found. Granitoid rocks intrude these groups and include the Topsails Igneous Complex (Taylor et al., 1980) and the informal Lloyds River intrusive suite (Kean, in preparation). Intrusive rock types include granites, granodiorites, quartz monzonites, quartz diorites, alkalic granites and gabbros.

Previous Work

Carboniferous rocks of southwestern Newfoundland have been studied intermittently for over a century since they were first identified by Jukes (1843) and Alexander Murray (1873; Murray and Howley, 1880).

Description and subdivision of the Carboniferous rocks began in 1873 when Murray identified two major subdivisions, the Mississippian Windsor marine series and the overlying, possibly Pennsylvanian, coal measures. He noted that five lithological sequences comprised these subdivisions. These five sequences correspond closely to more recently determined stratigraphic subdivisions (Table 1). Murray also measured a number of sections along Fischells Brook, in the coalfield of the St. George's Bay lowlands, and along the coast of the Codroy lowlands.

A three-fold subdivision of the Carboniferous into the Anguille, Codroy and Barachois Series was proposed by Hayes and Johnson (1938) and followed by Bell (1948) (Table 1). Both these investigations described the lithologies and fossils of the subbasin. The faunas of the Codroy Series, Bell (1948) noted, were molluscan-dominated, and the fossils were small and incomplete in comparison with those of the Windsor Group of Nova Scotia. Nevertheless, they enabled him to identify the presence of the Windsor marine fossiliferous subzones of Nova Scotia (Bell, 1929) in the Codroy Series. The shelly faunas in the subbasin thus have a close affinity to those found in northwestern European Viséan rocks (Bell, 1929) rather than to the faunas of Mississippian sedimentary rocks of continental North America. Bell (1948) also named many of the limestone units in the area and introduced names for some of the Codroy coastal sequences; for example, the Searston beds (Table 1). He also interpreted the depositional environments of the series and described the subbasin in a regional Maritime setting. The three series were redefined as groups by Baird and Cote (1964) and Cote (1964), who proposed a subdivision of the Anguille Group into three formations (Table 1) and divided the Codroy Group into lower and upper subdivisions. They described lithologies briefly and showed that rocks of the Anguille Group were nonmarine and included river-lain and lacustrine deposits.

Utting (1966) studied the fauna and microflora of the Searston beds and other strata in the Codroy Valley. He identified flora of Namurian A age in the Searston beds, Westphalian A age in coal beds near South Branch, and a marine fauna in other strata of Windsor age. The ages of coals in the subbasin were dated by Hacquebard et al. (1961) using miospores. They suggested that the coals of the Codroy Valley are slightly older than coal measures in the St. George's coalfield although both are Westphalian A in age.

Foraminifera were identified from the Crabbes limestone, St. George's Bay, by Mamet (1968), who suggested a Windsor subzone C age for the important marker bed. The foraminifera were shown to have the greatest affinity to those of the Arctic realm rather than Tethyan or North American faunas. He reported that "most species common to Newfoundland and western Europe are found in northern Siberia, Alaska, Yukon and the Canadian Arctic Islands". He came to a similiar conclusion in a broader study of the foraminifera of the Windsor Group of Nova Scotia (Mamet, 1970).

Since this study started in 1974, paleontological studies of shelly faunas (McGlynn, personal communication, 1979) and conodonts (von Bitter, 1975; von

Bitter and Plint-Geberl, 1978, 1979, 1982) have provided additional biostratigraphic information for the Codroy Group. Shelly faunas collected by McGlynn from limestones and shales of the Codroy Group generally substantiate the subzone determinations of Bell (1948). McGlynn has expanded the known faunal list and renamed many of Bell's species in accordance with recent fossil nomenclature for the Windsor Group (Moore and Ryan, 1976). Conodonts extracted from the many marine units of the Codroy Group have been subdivided into four faunal assemblage zones (von Bitter and Plint-Geberl, 1982) and correlated with the macrofaunal subzones of the Windsor Group.

Comparison of the Newfoundland Carboniferous with similar strata in the Maritime provinces was made in the earliest work by Murray (1873) and continued in later studies (Hayes and Johnson, 1938; Bell, 1948; Baird and Cote, 1964; Cote, 1964). The main conclusions were that the Anguille and Codroy Groups compared closely with the Horton and Windsor Groups of Nova Scotia.

Stratigraphy, sedimentology and tectonic setting were investigated later by Belt (unpublished report, 1966). He described lithofacies (Belt et al., 1967; Belt, 1968a), patterns of sedimentation (Belt, 1968a), and tectonic framework for the Carboniferous rocks in eastern Canada (Belt, 1968b) and also provided the basis for comparison of the Newfoundland Carboniferous with that of the northern British Isles (Belt et al., 1967; Belt, 1969). He showed a consistent pattern of sedimentation in both Newfoundland and the rest of the Maritimes. Alluvial fans formed adjacent to the subbasin margins and passed basinward into alluvial plain fluviatile sequences which in turn passed into lacustrine rocks in the center of the subbasin.

Maps of the Bay St. George subbasin have been produced by several workers at a number of different scales. The earliest maps are those of Hayes and Johnson (1938) which show the broad distribution of the three rock series with more detailed maps of the Codroy area and the St. George's coalfield. Bell (1948) produced small detailed maps of the Codroy area and the coast of St. George's Bay. Part of the Anguille Mountains was mapped by Baird and Cote (1964). The whole area was covered sparingly in 1:250,000 maps by Riley (1962) and Gillis (1972). A geological map of the St. George's Bay lowlands was prepared by Verrall (1954b) during a gravity survey. Structural studies have concentrated on marginal and intrabasinal faults (Phair, 1949; Belt, 1968b, 1969; Belt et al., 1969; Webb, 1969) and all suggest that the Long Range fault possessed a dextral strike-slip component of motion.

The presence of such potentially economic commodities as coal, industrial minerals, evaporites and base metals has lead to some important economic assessment studies in the area. After the discovery of coal by Jukes and Murray (Howley, 1897), much effort was expended on further discovery and description of the coal measures (Howley, 1897, 1913; Baker, 1927; Bryan, 1938; Summers, 1948; Hayes, 1949). The description and evaluation of the widespread gypsum deposits of the area (Baird, 1951, 1954, 1959; McKillop, 1953a and b, 1959) led to outlining reserves of about 300 million tonnes and establishing the currently operative Flat Bay gypsum mine in 1951. Fleming (1974) outlined the salt potential of the basin. Base metals and industrial minerals were briefly described by Johnson (1954), Riley (1962), McArthur (1973) and Fleming and McArthur (1976). Many of these reports also provide important geological information.

History of the Present Investigation

The rocks of the subbasin were systematically mapped on a 1:50,000 scale during the summers of 1974 and

1975 following a reconnaissance study of the rock types, stratigraphy and mineralization in 1973 (Stevens and Knight, 1974). For mapping, the subbasin was divided into two areas. The southwestern part, including the Anguille Mountains, Bald Mountain and the Codroy lowlands, was mapped by Knight (1975, 1976). The St. George's Bay lowlands were mapped by Fong (1974, 1976a and b; Fong and Douglas, 1975). Compilation and synthesis of the data collected became the responsibility of Knight after 1976. Since then, a number of short visits have been made to the area by the author in order to assist this compilation.

Aims of Study

The discovery of base metal mineralization in the area (Stevens and Knight, 1974), the delineation of a major Pb-Zn deposit in the Carboniferous rocks at Gays River, Nova Scotia, the presence of evaporites including gypsum and salt and the existence of only reconnaisance mapping in the area (Riley, 1962; Baird and Cote,1964; Gillis, 1972) provided the incentive to remap the subbasin. The aims of the study were:

A. to define, describe and date the lithostratigraphy of the subbasin;
B. to produce 1:50,000 scale geology maps;
C. to interpret the depositional environment;
D. to describe and interpret the structural history; and
E. to locate, describe and interpret the mineralization in the area.

CHAPTER 2

STRATIGRAPHY

Part 1 - Introduction and Stratigraphic Problems

Historically, the Carboniferous rocks of the Bay St. George subbasin have been divided into three rock series or groups - Anguille, Codroy and Barachois (Hayes and Johnson, 1938; Bell, 1948; Riley, 1962; Baird and Cote, 1964). Emphasis in previous work was on the palaeontological and economic aspects of the strata and only the Anguille Group was previously internally subdivided (Baird and Cote, 1964).

It will be shown that deposition in the narrow Bay St. George subbasin occurred predominantly by fluvial processes. Rapid changes of facies and diachronous boundary relationships are, therefore, to be expected. Sedimentation was controlled by an interplay of tectonics, climate and depositional environment. Such factors have been shown to make lithostratigraphic definition difficult in Cansoan and Riversdalian strata of Nova Scotia (Belt, 1965). Similar problems have been encountered in the Bay St. George subbasin (1) in the upper part of the Codroy Group, (2) in defining the Codroy/Barachois contact, and (3) in subdividing the Anguille Group.

Structural complexities which have destroyed continuity of the sequence, and poor exposure, especially at critical places in the section, compound the problems.

A descriptive approach is taken to the lithostratigraphy within the Carboniferous succession of the subbasin. Lithology and succession in formations, and in members if they occur within formations, as for example in the Robinsons River Formation, are described first in general terms. Detailed subdivision of the sedimentary rocks of each formation into lithofacies is then presented. In these specific instances, detailed descriptions of lithofacies allow interpretation of depositional environment for various rock types. Lithofacies here is used in accordance with definition b in the 'Glossary of Geology' (American Geological Institute, 1972, page 412), as "A term used by Moore (1949, p. 17 & 32) to signify any particular kind of sedimentary rock or distinguishable rock record formed under common environmental conditions of deposition, considered without regard to age or geologic setting or without reference to designated stratigraphic units, and represented by the sum total of the lithologic characteristics (including both physical and biologic characters) of the rock." In each case, the lithofacies were defined from detailed measured sections and from descriptions of rock types made during the course of field mapping.

Part 2 - Anguille Group

The Anguille Group, a sequence of nonmarine siliciclastic rocks, contains the oldest strata in the subbasin. It is mostly Tournaisian in age but also likely includes Upper Devonian strata, as first suggested by Belt (1968b, 1969). The group, which is defined lithostratigraphically, includes all Carboniferous strata that conformably underlie the basal Ship Cove Formation of the Codroy Group. The base of the group in the Anguille Mountains is not exposed; rocks assigned to the Fischells conglomerate member sit, however, unconformably upon Grenvillian basement in the core of the Flat Bay anticline.

The group was first divided formally into three lithostratigraphic units by Baird and Cote (1964) but the stratigraphy is revised here to four formations (Table 1). This is necessary because some important structural complexities were overlooked by Baird and Cote (1964). For example, their basal unit of red sandstones and slates, the Cape John Formation, can be shown to be inverted structurally and belongs instead to the uppermost redbed sequence of the group called the Spout Falls Formation in this report. The basal unit of the Anguille Group is redefined and renamed the Kennels Brook Formation. The Snakes Bight Formation of Baird and Cote (1964) is retained, but their Seacliffs Formation is now subdivided into two formations, the Friars Cove Formation and Spout Falls Formation.

Distribution

The Anguille Group (Figure 4) occurs in the following areas:

(a) in the Anguille Mountains, and Bald Mountain and northeastward adjacent to the Long Range fault as far as Barachois Brook;
(b) in the core of the Flat Bay anticline between Robinsons River and Flat Bay Brook;
(c) adjacent to the Steel Mountain anorthosite on Coal and Sheep Brooks;
(d) as thin deposits in the Port au Port - Stephenville area.

In the Anguille Mountains, all four formations of the group have been mapped. They are all present towards the northern end of the mountains and within the sequence northwest of the Snakes Bight fault. The uppermost Spout Falls Formation, however, is absent in the southeastern part of the Anguille Mountains. Here the Friars Cove Formation continues to the top of the group but contains some thin intercalations of strata typical of the Spout Falls Formation.

The four formations, as defined, are not recognizable in the Flat Bay anticline where the Anguille Group is represented by the Fischells conglomerate member (Baird, 1959). The relationship of this unit to the main Anguille succession to the south is still uncertain. Scant lithological evidence, however, suggests it is correlative with at least the upper part of the Spout Falls Formation, to which it is assigned (see also Baird and Cote, 1964). In the north of the subbasin on the Port au Port Peninsula and near Stephenville, thin conglomerate lies upon basement and beneath basal limestones of the Codroy Group and is also included in the Anguille Group.

Basal arkoses that underlie a local unconformity within the Brow Pond lentil (Figure 4) may be of equivalent age to part of the Spout Falls Formation. There is yet no biostratigraphic evidence to support this correlation.

Thickness

The thickness of the Anguille Group in the Anguille Mountains northwest of the Snakes Bight fault is approximately 2000 m. Southeast of this fault (Figure 4), the group thickens to at least 4000 m in the northeast of the mountains but thins rapidly southwestward to about 2800 m as the Spout Falls Formation lenses out. In the southwest, a deep drill hole in the Kennels Brook Formation provided evidence for an additional 2275 + m to the section in this area. Here 3300+ m of the 4900+ m thick sequence, however, consists of the basal Kennels Brook Formation. In contrast, in the northeast of the Anguille Mountains the 4500 + m succession is dominated by the 3500 m thickness of the youngest Anguille formations, the Friars Cove and Spout Falls Formations. Significantly, this implies that the group is made up of basin-fill sequences of essentially two different ages.

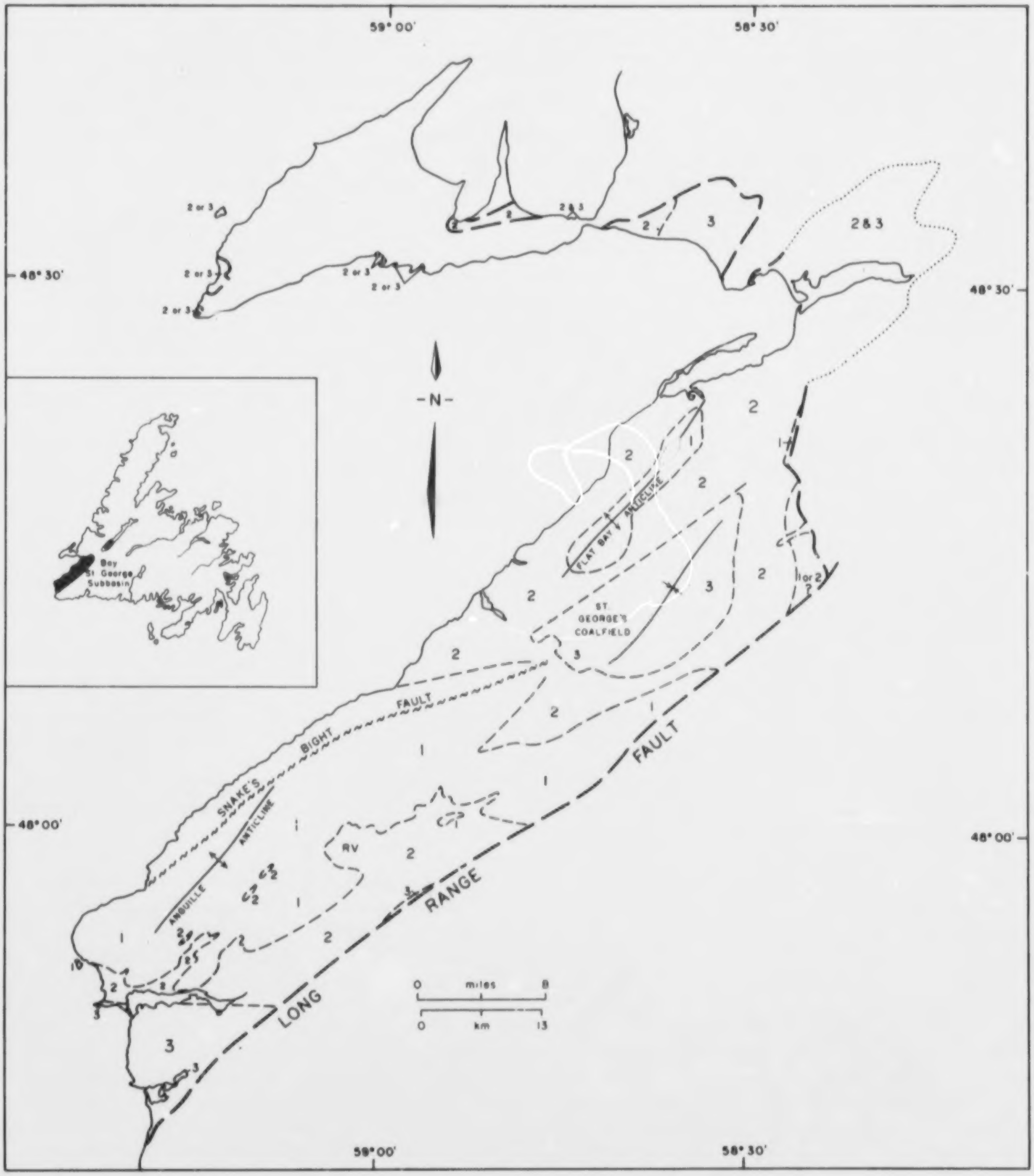
The Fischells conglomerate member in the Flat Bay anticline is approximately 150-200 m thick, whilst only 1-2 m of conglomerate occurs along the northern margin of the subbasin.

Description of Formations

Kennels Brook Formation

Definition, distribution and thickness

The basal formation of the Anguille Group consists of red and gray


59° 00'
58° 30'
48° 30'
48° 00'
-N-
2 or 3
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2
3
1
1 or 2
SNAKE'S BIGHT FAULT
LONG RANGE FAULT
FLAT BAY ANTICLINE
ANGUILLE ANTICLINE
ST GEORGE'S COALFIELD
RV
0 miles 8
0 km 13
Bay St George Subbasin

Figure 4: Distribution of groups in the Bay St. George subbasin: 1 - Anguille Group; 2 - Codroy Group; 3 - Barachois Group. (R.V. - "round valley")

sandstones, pebbly sandstones, conglomerates and slates with some brown mudstone and siltstone, and is here named the Kennels Brook Formation. It outcrops in the core of the Anguille anticline, along the base of the cliffs south of Snakes Bight, and as a narrow, linear belt of rocks immediately northwest of the Snakes Bight fault. The formation is not well exposed and hence no type section is designated. The name is derived from Kennels Brook, which transects part of the unit and drains into Snakes Bight. The best exposures are found along Hynes Gulch, and Mary Ann's Gulch in the cliffs at Snakes Bight, where the uppermost beds of the formation are exposed. The base of the Kennels Brook Formation is not exposed in the area. A drill hole of 2275 m depth, sited on the crest of the Anguille anticline, did not reach the base of the unit (Union-Brinex, 1973). The top of the formation is placed at the first appearance of black shales in the overlying Snakes Bight Formation. The upper contact, which is well exposed at the base of the cliffs south of Snakes Bight, is sharp and apparently conformable, although locally it has been affected by thrust faulting. In this area, interbedded brown mudstones and siltstones compose the upper beds of the formation. Around the Anguille anticline, these lithologies are absent, and the top of the formation consists of green-gray to red sandstones and red siltstones.

The Kennels Brook Formation is at least 3200 m thick; 1000 m is exposed and the remaining thickness was penetrated in the Union-Brinex (1973) drill hole. Cote (1964) measured some very generalized sections on Lewis Gulch (246 m thick), at Hynes Pond on the crest of the Anguille anticline (714 m) and along the south side of Snakes Bight (92 m).

General lithology

The exposed portion of the Kennels Brook Formation consists of (A) brown weathering, well indurated, green-gray sandstones, pebbly sandstones and conglomerates, (B) red sandstones, red and green slates containing nodular caliche, and (C) brown silty mudstones and very fine sandstones, and a thin, discontinuous pale gray limestone bed.

Description of lithologies from the Union-Brinex drill hole (Union-Brinex, 1973) show similar rock types occur in the underlying succession. Fining-upward sequences of intercalated gray to red sandstone and red slates dominate thick intervals (up to 600 m). Other intervals up to 200 m thick consist of mostly gray and red, gritty and pebbly sandstones without red slates. Encountered at several levels in the drill hole, particularly in the lower 1000 m, are units up to 80 m thick of dolomitic, gray to green-gray, waxy shales and thin sandstones.

(A) *Gray-green sandstone and conglomerate*

The oldest strata exposed in the core of the Anguille anticline consist of thick units of green-gray, coarse grained sandstones and some pebbly sandstones and conglomerates. The coarse members are intercalated with thin units of red and green slates.

The arkosic and micaceous sandstones commence above a basal scour into the intercalated slates. The sandstones are generally massive with some lamination or thin bedding. Asymmetrical linguoid and sinuous-crested ripples are found that resemble the cuspate current ripples of Gustavson (1974) and the ripples of facies C_1 of the Donjek River (Williams and Rust, 1969). They are rare, and in some instances, covered by thin, locally discontinuous mud drapes.

The conglomerate and pebbly sandstone members are poorly sorted and consist of 5 to 36 cm thick beds. The pebbly sandstones are crudely interstratified with the conglomerates. Together they form layers, lenses and scour infills within the sandstones. The pebbles are well to moderately rounded (Powers, 1953) and from 3 to 12 cm in diameter. They consist of white quartz, pink, finely crystalline, micaceous granite, coarsely crystalline pink granite, red granites, red hornblende granite, brown and red aphanitic rhyolite, banded rhyolite, brecciated rhyolite, green siliceous siltstone and an occasional pebble of coarse grained, green sandstone and pale gray granite gneiss. The largest clasts are generally white quartz. The interbedded red and green slates, which are up to 40 cm thick, overlie the sandstone members sharply. They appear to lack internal sedimentary structures.

(B) *Green to red sandstones and slates*

Green, green-gray to red sandstones and red and green slates replace the coarser beds upwards in the formation. The 1 to 3 m thick sandstones are fine to medium grained, arkosic and micaceous. They overlie erosional bases and fine upwards. Internal bedding is generally obscure but planar lamination, thin stratification, some large scale, planar-tabular crossbedding and trough crossbedding were noted. Trough crossbeds, 3 m wide and 50 cm thick at the base of the sandstones, decrease in size upward to 10 cm thick, 20 cm wide sets near the top of the beds. Dark gray shale clasts are common within the crossbedded sandstones.

The red and green slates, in units up to 6 m thick, are generally structureless, but ripple cross-laminations, horizontal laminations, small yellow calcareous nodules (caliche) and mudcracks infilled locally with calcium carbonate are visible in some.

(C) *Brown mudstones and sandstones*

In the southwest of the Anguille Mountains, brown mudstones, very fine sandstones and green siltstones form a sequence 12 to 90+ m thick above the gray and red sandstones and slates. The unit is wedge shaped and thickens southwestwards beneath the Snakes Bight Formation. It attains its maximum thickness of 90 m at Snakes Bight (Cote, 1964; Baird and Cote, 1964), thins to approximately 59 m at Hynes Gulch northwest of the Snakes Bight Fault, and is only 12 m thick (Cote, 1964) at Lewis Gulch. The unit is absent, however, beneath the Snakes Bight Formation along the headwaters of Brooms Brook on the southeast limb of the Anguille anticline. Here, black shales of the Snakes Bight Formation directly overlie gray and red sandstones and slates. The base of the unit is not exposed but red siltstones, which are more common towards the base of the Snakes Bight section (Cote, 1964), suggest that it grades downwards into the underlying gray and red sandstones and slates. Bedded green siltstones typify the Hynes Gulch and Lewis Gulch sections suggesting that the interbedded brown mudstones and very fine sandstones are confined to the area near Snakes Bight.

Brown weathering, very fine sandstones occur in 10-40 cm thick beds and overlie planar to irregular bases, which in certain localities display scoop-shaped, shallow, and crosscutting forms. Internally, the sandstones display lamination which is often undulose. Ripple cross lamination and climbing ripple drift of types A and B (Jopling and Walker, 1968) also occur. Convolution of the cross-lamination is common and dark brown liesegang rings are present in some of the sandstones.

Partings and beds of gray silty mudstone, a few centimetres to 75 cm thick, are interbedded with the sandstones. The generally massive mudstones weather with a poorly developed, hackly fracture, but, in some places, have a crude fissility. They contain a few lenses and boudinaged beds of green-gray siltstone. Mudcracks occur in the top of the mudstone and in the partings between sandstone beds. Rainprints are associated with some mudcrack horizons.

A single bed of laminated, shaly, pale gray limestone, 170 cm thick, occurs within the brown mudstone member in Mary Ann's Gulch, northwest of the Snakes Bight Fault. Alternating laminae of microspar and silty microspar form the laminations which are discontinuous and locally convoluted. The convolutions were flattened into the plane of the lamination during folding of the Anguille Group. No concretionary structures or fossils were found. Three kilometres to the northeast at Hynes Gulch, nodular gray limestone within laminated, very fine sandstones and siltstones appears to represent an extension of the unit. The nodular limestone is composed of very fine microspar with only scattered, angular, detrital silt grains.

Unlike the description of lithology in succeeding formations, the Kennels Brook Formation has not been further divided into lithofacies.

Age and correlative deposits of the Kennels Brook Formation

The exact age of the formation is uncertain. The author is, however, in agreement with Belt (1968b, 1969) in suggesting that the Kennels Brook Formation are equivalent to the pre-Hortonian strata in Nova Scotia which are, in part, Late Devonian in age. This inferred pre-Hortonian age was based on miospores (Belt, 1969) presumably found in the single sample described by Cote (1964). The greater thickness of basal Anguille strata in the Bay St. George subbasin when compared to equivalent strata in the Horton Group of the Maritimes Basin supports a longer period of deposition and strengthens the suggestion of a Late Devonian age.

Cote (1964) and Belt (1968b, 1969) correlated the Kennels Brook Formation with the Craignish Formation of Cape Breton. In New Brunswick, redbeds of the Memramcook Formation (Varma, 1969) and the Perry Formation (Schluger, 1976), both Late Devonian in age, may be correlatives of the Kennels Brook Formation.

Elsewhere in Newfoundland, post-Acadian redbeds of Devonian age are found at a number of isolated localities. On the west coast of the island, the Lower Devonian Clam Bank Formation (Rodgers, 1965; O'Brien, 1975) occurs on the Port au Port Peninsula. Redbeds are also known along the south coast of Newfoundland in the Fortune Bay (Calcutt, 1973), Gaultois (Greene and O'Driscoll, 1976), Harbour Breton (Greene, 1975), and Terrenceville (Bradley, 1962) areas. The Bay de l'Eau and Terrenceville Formations are dated by miospores as Late Devonian (Widmer, 1950; Bradley, 1962) and may correlate with the Kennels Brook Formation. These formations indicate the presence of regional molasse sedimentation peripheral to a central Newfoundland upland similar in shape to present-day Newfoundland.

Depositional environment of the Kennels Brook Formation

Both Cote (1964) and Belt (1968a, 1969) interpreted the strata now assigned to the Kennels Brook Formation as fluviatile sediments. Belt (1968a) included them in his coarse grained fluvial facies positioned midway between basin-margin fanglomerates and finer basinward fluvial facies. The character of the succession suggests deposition by braided and meandering rivers, except locally at the top of the formation where the succession includes shallow lacustrine sediments in the southwest.

Massive or crudely stratified, scour-based, pebbly coarse sandstones, in the lower part of the formation suggest deposition by gravelly and sandy braided streams (Rust, 1972; Miall, 1977). The structure and grain size of the coarse beds suggest that they were deposited as longitudinal bars during the high stage of stream floods (Doeglas, 1962; Williams and Rust, 1969;

Smith, 1970, 1974; Rust, 1972; Miall, 1977). Structures typical of waning flood stages are rare. This, together with the fact that the contacts between sandstones and overlying red slates are sharp, may indicate rapid termination of stream flow in ephemeral streams. Minor mud-draped rippled surfaces and red slate layers probably formed in abandoned or minor channels in the braided channel system (Williams and Rust, 1969; Rust, 1972).

The repetitive character of the thick red sandstone - thick red slate succession in the middle of the formation suggests that the fluvial system later became a mature flood plain crossed by meandering rivers. The graded sandstones have basal scours, mudchip pebbles, parallel lamination and cross stratification. Sedimentary structures decrease in size upward, and the sandstones are overlain by red lutite. This sequence compares to the classical fining-upward cycles of Allen (1964a, 1965a, 1965b) deposited by lateral accretion beneath point-bar complexes of meandering rivers. Oxidized overbank deposits, represented by thick red lutites, were deposited on the flood plain. Nodular carbonate suggests immature caliche, typical of pedogenic horizons that form in soils under semiarid climatic conditions (Gile et al., 1966; Blatt et al., 1972; Leeder, 1975).

Although no paleocurrent data was obtained, the arkosic composition of the sandstones and the dominantly acid-plutonic and silicic-volcanic clast composition of the pebbles suggest the source of alluvium was from pre-Carboniferous crystalline and volcanic rocks of central Newfoundland.

The bedded mudstones and very fine sandstone at the top of the formation form a wedge-shaped rock body in the southwest of the area and were probably deposited in a shallow lacustrine environment. This model cannot be supported by paleontological evidence or by definitive lithological features. The strata are restricted geographically to the present environs of the Snakes Bight fault, which is consistent with a narrow lake trending northeastward, particularly if the fault was active during deposition. Mudcracks that developed in both mudstone and sandstone units indicate that parts of the lake bed were periodically exposed. Rhythmic deposition of sandstones and mudstones point to alternating flood and interflood deposition. The tabular geometry, planar lamination and climbing ripple-drift lamination in the sandstones suggest that large volumes of fine sand were transported during floods and rapidly deposited as sheets over the muds (McKee, 1965). The sheets perhaps formed as floodwaters breached channels that cut across exposed dessicated mudflats. Lake level rose during each flood to drown the sand sheets and the lake margins and led to subsequent deposition of suspended mud. Laminated limestones were locally precipitated in the shallow lake waters. Nodular limestone formed pedogenically in porous sandstones when the lake level periodically fell as a result of evaporation in the semiarid climate (Gray, 1967; Freytot, 1973).

Snakes Bight Formation

Definition and distribution

The Snakes Bight Formation was the name proposed by Baird and Cote (1964) for a sequence of black lutites and gray sandstones of lacustrine origin that conformably overlie the Kennels Brook Formation. The formation derives its name from Snakes Bight, a small cove north of Cape Anguille. The formation occurs in the northwest dipping, faulted limb of the Anguille anticline and to the southeast of the Snakes Bight fault, where it is folded about the Anguille anticline between the fault and Brooms Brook. The upper beds of the formation are repeated along high angle faults near Cape Anguille and at the northeastern closure of the Anguille anticline. The type section is located along Hynes Gulch beginning about 2 km upstream of the mouth and continuing downstream for approximately 1.2 km (Figure 5 on foldout sheet A).

The formation begins where the black shales overlie either redbeds, as around the southeast limb of the Anguille anticline, or brown mudstones, sandstones and green siltstones as in the southwest of the Anguille Mountains and just northwest of the Snakes Bight fault as far north as Lewis Gulch (Cote, 1964). At Snakes Bight the basal contact is sharp and was probably originally conformable, although it has been locally thrust. Elsewhere in the Anguille Mountain, the basal contact is not exposed, although the interval that conceals the contact on the south branch of Brooms Brook is only a few metres wide. The absence of brown mudstones and sandstones at this locality and elsewhere around the Anguille anticline may suggest the basal contact locally onlaps the underlying Kennels Brook formation. The upper contact is generally conformable and is placed at the base of a series of conglomerate beds which mark the base of the Friars Cove Formation throughout the Anguille Mountains.

Thickness

A section measured along Hynes Gulch indicates that the Snakes Bight Formation is about 785 m thick northwest of the Snakes Bight Fault. Southeast of the fault it is estimated to be 1000 m thick.

General lithology

The sedimentary rocks of the Snakes Bight Formation include black shales and mudstones, thin bedded siltstones, thin and thick bedded gray sandstones, minor conglomerates, intraformational slump deposits and minor dolomitic and calcareous mudstones, argillaceous and arenaceous calcisiltites and calcarenites, and calcareous concretions. The sandstones are brown weathering, lithic arkoses to subarkoses; conglomerates consist of 1-3 cm diameter pebbles composed almost exclusively of white quartz and dolomite intraclasts.

The succession in the type section at Hynes Gulch and elsewhere northwest of the Snakes Bight fault consists of units of black lutite up to 27 m thick intercalated with sequences of interbedded sandstone and shale, up to 35 m thick. The sandstones have the general characteristics of turbidites (Bouma, 1962). Units of thick bedded massive sandstones with pebble layers as great as 50 m thick are dispersed through the section.

The black lutites and interbedded sandstones and shales are concentrated in the lower 350 m of the type section. They are generally succeeded by thick intercalated units of mudstones and thick bedded sandstones with only subordinate interbeds of sandstone and shale. In the upper 100 m, some of the thicker sandstones display crossbedding. Coarsening-upward sequences of mudstone overlain by thick sandstones are common in the upper 500 m. Shales become grayer in color and some evidence of subaerial exposure and dessication was observed locally near the top of the formation.

In the southwest of the area overlooking Snakes Bight, in Low Brook, Grebes Gulch and the Brooms Brook headwaters, the succession is broadly similar, commencing with some 60 m of thin-bedded siltstones, black shales and minor sandstone. This sequence passes upwards into generally monotonous, rhythmically interbedded sandstones and shales for at least 500 m (Plate 1). Chaotic deposits of intraformational mixtites are common particularly in the lower levels of the formation. The sandstones have the overall characteristics of turbidites and resemble Carboniferous flysch sequences of the Ouachita fold belt (Morris, 1974), southwest England (personal observation) and northern England (Walker, 1966a, 1978). Thick sandstone units interrupt the succession at intervals and

Plate 1: Cliff section just north of Low Brook, Snakes Bight. Section includes some thick bedded sandstones (lithofacies C) interbedded with bundles of turbidite sandstone and shale (lithofacies B), some of which thicken upwards. Cliff about 60 m high.

coarsening-upward sequences of black lutites overlain by thick bedded sandstones are also common (Plates 2 and 3). Toward the top of the Snakes Bight Formation in the southwest of the area, the thick coarsening-upward sequences are associated with sequences up to 12 m thick of laminated mudstones and siltstones containing rare sandstone beds. Thin dolomitic carbonates are also common. Here the upper sequence of the formation yields evidence of bioturbation and local dessication similar to that found in the type area near Snakes Bight.

Six lithofacies have been identified in the Snakes Bight Formation. They are (A) black mudstone-shale lithofacies, (B) graded sandstone/siltstone - shale lithofacies, (C) thick bedded sandstone lithofacies, (D) thinly bedded sandstone - shale lithofacies, (E) intraformational mixtite lithofacies and (F) carbonate lithofacies.

(A) BLACK MUDSTONE - SHALE LITHOFACIES

Description of lithofacies A: This lithofacies, which comprises from 25 to 29% of the type section (Figure 5 on foldout sheet A), is distributed throughout the formation. It consists of black, finely laminated and massive carbonaceous mudstones, siliceous mudstones and black shales in units 50 cm to 27 m thick. Both mudstones and shales are dolomitic and pyritiferous with microcrystalline dolomite making up 5 to 50% of the whole rock.

The laminated mudstones are composed of well to poorly sorted, microscopically graded, muddy siltstones and silty mudstones. The mudstones are rich in carbonaceous material and are black. Delicate, carbonaceous, pyritic and yellow weathering, ferruginous dolomite laminae also occur. Small rounded and flattened pores are filled by microcrystalline dolomite. The dolomitic and siliceous nature of the laminae produces flat to undulose, smooth-surfaced outcrops that have a brittle, platy fracture. Light colored siltstone and sandstone laminae, 1 mm thick, are found in many units and are replaced upward in coarsening-upward, mudstone - sandstone sequences by 1-10 cm beds of flat-bedded, finely laminated and rarely

Plate 2: Lithofacies A black shale and laminated mudstone at the base of a coarsening-upward sequence within the Snakes Bight Formation at Cape Anguille. Note steady upward increase of thin sandstone and siltstone beds.

Plate 3: Thick bedded, massive sandstone (lithofacies C) forming top of coarsening-upward sequence in the Snakes Bight Formation at Cape Anguille. The sandstones overlie interbedded shale and flute-bearing turbidite sandstones which in turn overlie planar, flat bedded, very fine sandstones, siltstones and thin black shales.

Plate 4: Dolomite beds and laminae in black mudstones (lithofacies A) from the top of the Snakes Bight Formation near Cape Anguille lighthouse. The sediments are deformed by synsedimentary folds.

cross-laminated siltstones and sandstone.

Soft-sediment deformation (Plate 4) locally produced synsedimentary folds, faults, and brecciation. Fold axes at Cape Anguille strike approximately N-S and axial planes dip to the west from 25° to 70°. Sandstone dikes, which are a few centimetres to 140 cm wide and cross-cut at least 3 m of strata, occur at the top of the formation near Shoal Point, Codroy.

Mudcracks were noted at the base of sandstones intercalated with the laminated mudstones just below the upper contact of the formation at Friars Gulch and Hynes Gulch (Figure 5 on foldout sheet A). Mudcracks were not observed lower in the formation.

Interpretation of lithofacies A: Delicate lamination, lack of current-generated structures and the presence of pyrite and carbon-rich laminae suggest that the black mudstones and shales were deposited from suspension in stagnant, fetid waters. Structures in the mudstones are similar to those formed in quiet basinal deposits of flysch basins (McBride, 1962) and in deeper water deposits of ancient and modern lakes (Ludlam, 1967, 1974; Sanders, 1968; Dineley and Williams, 1968; Belt, 1968a; Donovan, 1975; Hubert et al., 1976; Sturm and Matter, 1978). Siltstone and sandstone laminae and flat bedded, thinly laminated sandstones and siltstones in the mudstones, are probably distal turbidites (Walker, 1967) or deposits of other low density flows (Sturm and Matter, 1978).

Syndepositional deformation locally affected some units, formed folds and faults, and may have triggered the injection of sedimentary dikes, suggesting that the depositional environment was unstable and possibly frequently jolted by earth movements.

Mudcracks in mudstones near the top of the Snakes Bight Formation suggest subaerial exposure in the late stages of the evolution of the formation. However, these structures may be synaeresis (dehydration) cracks which can form subaqueously (Burst, 1965; Donovan and Foster, 1972). No other evidence of

Plate 5: Siltstone-shale beds of lithofacies B, Snakes Bight Formation. The shales exhibit gently dipping upward-facing cleavage. Thicker beds at base are fine sandstones, internally deformed, with irregular bases. Unnamed brook near Snakes Bight.

dessication was found, so that subaerial exposure cannot be proven for intervals of this facies near the top of the formation.

(B) GRADED SANDSTONE/SILTSTONE-SHALE LITHOFACIES

Description of lithofacies B: This lithofacies consists of graded sandstone or siltstone beds regularly alternating with black shales. It constitutes 32% of the type section (Figure 5) and is also the major lithofacies in the first 300 m of the Snakes Bight Formation in the southwest part of the Anguille Mountains. Here the facies commences with up to 60 m of graded siltstone-shale beds, with some thin, graded sandstone beds, and is overlain by a fairly continuous sequence of graded sandstone-shale beds.

Siltstone-shale beds are 25-45 cm thick, of which 3-10 cm is siltstone (Plate 5). These dark gray, structureless beds overlie sharp, nonerosive, planar to slightly undulose bases. They grade upward into structureless, dark gray and black mudstones.

Sandstone-shale couplets form beds 15 to 50 cm thick, of which 10-40 cm are sandstone. Similar sandstones, 3-10 cm thick, occur in the siltstone-shale sequences. Cliff sections show that lateral continuity of beds is good (Figure 6; Plate 1). The sandstones are poorly sorted and vary from very coarse to very fine grained. They are predominantly medium grained in the northeast but appear to be finer grained in the southwest of the area.

The bases of the sandstones are usually sharp and planar but they also can be erosive and irregular. Nonerosive, sharp bases characterize the thin sandstones in the siltstone sequence. Sole markings occur and include linguiform, fan-shaped and crescentric flutes (Enos, 1969), chevron marks (Dunbar and Rodgers, 1957), longitudinal ridges (Dzulynski and Walton, 1965), groove casts and discontinuous grooves. Load casts are common and hieroglyphs are in many instances modified by soft-sediment deformation. The tops of many sandstones are sharp.

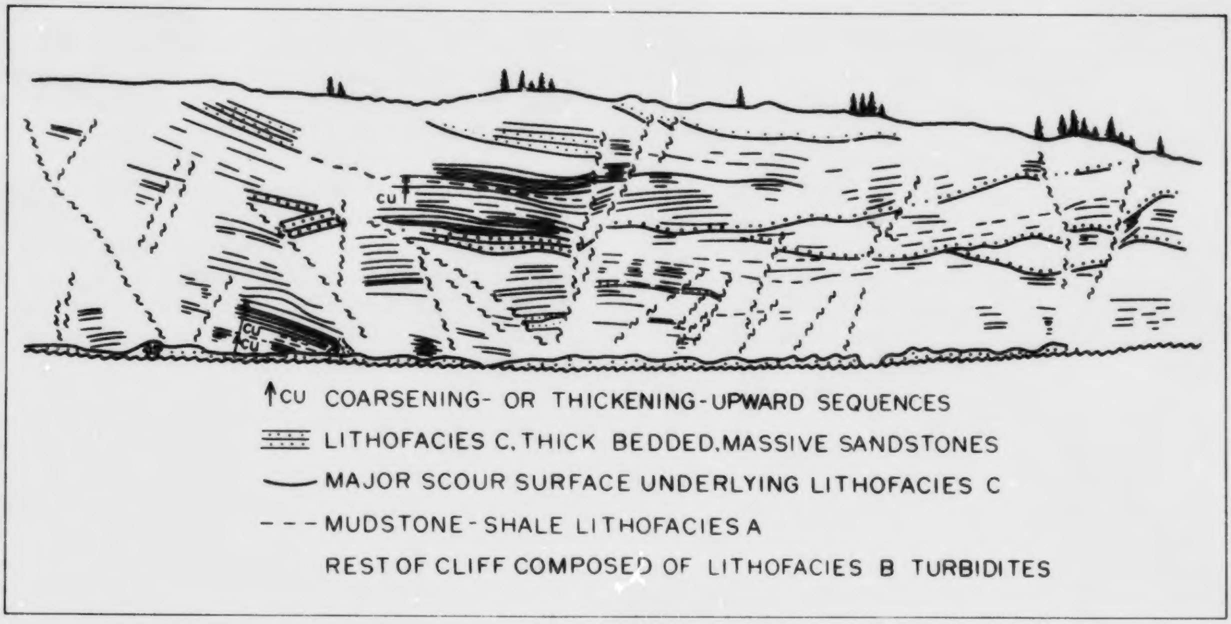

CU
CU
CU
↑CU COARSENING- OR THICKENING-UPWARD SEQUENCES
▤ LITHOFACIES C, THICK BEDDED, MASSIVE SANDSTONES
—— MAJOR SCOUR SURFACE UNDERLYING LITHOFACIES C
- - - MUDSTONE-SHALE LITHOFACIES A
REST OF CLIFF COMPOSED OF LITHOFACIES B TURBIDITES

Figure 6: Line drawing from photographs of cliffs overlooking Snakes Bight, just north of mouth of Low Brook. Strata of the Snakes Bight Formation contain major erosion surfaces that are mostly overlain by lithofacies C sandstones interspersed through thick sequence of turbidite sandstones (lithofacies B).

The thinner sandstones, particularly those interbedded with the graded siltstones, are internally composed of planar lamination and small scale cross-lamination. Sandstones of the rest of the succession, however, are normally graded and generally structureless. In the coarser beds, grading occurs from coarse or medium grained sandstone at the base to clean or muddy fine sandstone at the top. Mudclasts occur in some of these beds. Planar lamination and cross-lamination occur in the upper 3 to 10 cm of some beds, whilst others are formed exclusively of parallel lamination. Convolution of internal structure is common in both siltstones and laminated sandstones. Examination of photographs of the cliff sections from Snakes Bight to Cape Anguille suggests some graded beds occur in both coarsening- and fining-upwards bundles. On the other hand, in some parts of the sections, no trends are obvious.

Interpretation of lithofacies B: The rocks of this facies are similar to the monotonously interbedded classical turbidites and shales of silty and sandy flysch (McBride, 1962, 1970; Cline, 1970; Walker, 1970, 1978, 1979b; Walker and Mutti, 1973; Morris, 1974). Sandstones are typified by sharp bases, abundant sole marks and grading.

Most of the turbidites of this facies are classed as proximal AE or ABE turbidites (Bouma, 1962), because they are dominated by the massive interval A of the Bouma sequence (Walker, 1967). In contrast, the less common, flat-based, planar and cross-laminated BCE turbidites of the facies (Bouma, 1962) may have been deposited by waning turbidity currents (Normark, 1974), or by smaller flows.

The abundance of turbidites points to deposition in a deep basin below wave base. Such a base could have been marine or a deep lake (Gould, 1951, 1960; Houbolt and Jonker, 1968; Lambert et al., 1976; Sturm and Matter, 1978).

(C) THICK-BEDDED SANDSTONE LITHOFACIES

Description of lithofacies C: Units up to 15 m thick, composed mostly of thick bedded, massive sandstones make up this lithofacies and comprise about 18% of the type section. In addition, some stratified and crossbedded units occur, as do layers of conglomerate and pebbly sandstone. The facies is recognizable at intervals within the thick sequences of lithofacies B (Plate 1). In cliff sections at Snakes Bight, the sandstones are found above major concave-up scours more than 270 m wide, cross-cutting as much as 10 m of underlying lithofacies B strata (Figure 6). The facies also forms the most coarse, highest member of general coarsening-upward sequences (Plates 2 and 3). The thick bedded sandstones then thin and fine upward into lithofacies B turbidites, or are abruptly overlain by facies A mudstones.

The main sandstone units are constructed of beds 30 to 100 cm thick separated only by shale partings. Sandstone beds are poorly sorted, ungraded or graded, coarse or medium to fine grained. They usually overlie sharp, erosive bases; planar to cross-cutting bedding planes and channelling are common within units. Sole markings include bulbous flutes, frondescent marks (Dzulynski and Walton, 1965), groove casts and load casts. Internally, the beds are generally massive, though faint color variations and rare lamination suggest the presence of some amalgamated beds.

Intraclasts of shale and laminated dolomite, and granules of white quartz, rare silicic volcanics and granite are scattered in some sandstones. They may form pebbly sandstones and rarely conglomerates up to 70 cm thick in the middle of some units. Pebbles, mostly 1-3 cm and rarely 6 cm in diameter, are subrounded to angular. The intraclasts reach 20 cm in size but most are less than 10 cm in diameter and are flat and discoidal. Crude grading may be found in some pebbly beds. Crossbedding and planar stratification are present in thick sandstones that lie above thin-bedded turbidites and gray shales (lithofacies D) and below the basal conglomerate member of the Friars Cove Formation on Friars and Hynes Gulch. The 10-40 cm thick crossbeds occur as isolated or composite sets scouring into the underlying stratification. Three-dimensional exposures of the crossbeds, though uncommon, reveal trough-shaped sets.

Interpretation of lithofacies C: The thick bedded, massive character of many of the sandstones and their association with turbidites suggest that most of lithofacies C was deposited rapidly by mass emplacement of sandy detritus from dense turbidity currents or sandy debris flows (Middleton and Hampton, 1973, 1976).

Some of the thick bedded sandstones overlie major scours within the turbidite sequence, possibly indicating deposition in channels or major episodes of basin instability which produced influxes of sand by slumping. The presence of coarsening-upward sequences capped by massive sandstones, however, suggests that deposition was associated with prograding deltas (Coleman, 1976) or with prograding sandy, deep water fans (cf. Walker, 1978) at the foot of delta slopes (Normark and Dickson, 1976a,b). The coarsening-upward sequence at the top of the type section of the Snakes Bight Formation shows thick sandstones, with current structures typical of fluvial processes. This evidence suggests that large, prograding, sandy deltas were common in the basin. Coarsening-upward sequences overlain sharply by mudstone or gradationally by thinner-bedded turbidites of facies B suggest that the delta-front or deep water fan deposits were both abruptly and gradually abandoned. Abandonment may have been affected by channel switching or by reducing the sediment discharge along feeder channels.

(D) THINLY BEDDED SANDSTONE-SHALE LITHOFACIES

Description of lithofacies D: This lithofacies consists of thin bedded, often rusty weathering, very fine sandstones or siltstones interbedded with thin, black or gray shales. It forms only 5% of the type section. For the most part these lithologies alternate every few centimetres, but the beds also pinch out laterally. Sandstone beds are bounded by flat bedding planes with sharp tops. Most of the sandstones are cross-laminated or display parallel lamination overlain by cross-lamination; massive sandstone occurs at the base of some of the thicker beds. Soft-sediment deformation commonly produced load casts and flame structures as well as convolution of internal structures. Wavy bedding, boudinage, pseudonodules, wrinkling of bedding planes and linear, sand-filled cracks are common in the thin bedded sequences. Fine plant debris and detrital micas are widespread.

This lithofacies is found in association with the thick sandstones of facies C in the type section of the Snakes Bight Formation and it also underlies the basal conglomerates of the Friars Cove Formation at Cape Anguille.

Interpretation of lithofacies D: The thinly bedded, very fine grained sandstones and shales include many features suggesting rapid deposition on levees that lay adjacent to a deep water channel along which sandy turbidity currents were funnelled (Mutti, 1977). This is supported by the presence of thin shales, the abundance of deformation, indicating rapid deposition, the wrinkling of bedding and the occurrence of linear cracks both possibly related to slope creep (tension), and the close association of the thinly bedded lithofacies with the coarsest deposits of the Snakes Bight Formation (Walker, 1966b; Ricci Lucchi, 1975; Mutti, 1977).

Facies D is also overlain gradationally by crossbedded and stratified sandstones in coarsening-upward sequences near the top of the formation. Here, the thin bedded sandstones and shales may be interpreted as prodelta deposits laid down in front of advancing distributary-channel sandstones (Coleman and Gagliano, 1965; Coleman, 1976).

(E) INTRAFORMATIONAL MIXTITE LITHOFACIES

Description of lithofacies E: Small scale, synsedimentary deformation of both the fine and coarse sediments occurs throughout the formation. Larger scale, more extensive deformation, however, resulted in the formation of intraformational mixtite deposits. They are particularly common in the lower part of the formation in the southwest of the area where they comprise only a few percent of the sections of which they are a part. Here they lie within the turbidite sequences, in some places immediately beneath major scours.

The mixtites are up to 6 m thick. At one extreme they are composed of small, mostly mudstone intraclasts set in a mud matrix (Plate 6). At the other extreme they consist of an unsorted, chaotic mixture of large (up to 1 m in diameter) broken, boudinaged, attenuated, contorted, folded and rolled clasts all set in a muddy matrix. Lithologically, the clasts include sandstone, siltstone, shale and laminated dololutite (Plate 7). Shale and laminated fragments usually have ragged and tapered edges, whilst sandier intraclasts are smooth but angular. In rare instances fragments appear to be oriented. Near the top of one mixtite deposit, coherent sandstone beds were deformed to form tight, recumbent folds (Plate 8) which trend northeast. Irregular and transgressive bases occur but it is not unusual to observe undeformed, nonscoured sediments below the units. Some fine mixtite beds, about 60 cm thick, have erosive bases and grade upward into shales. They are intercalated with the turbidite sandstones.

Plate 6: Lithofacies E intraformational mixtite consisting of small fragments of laminated mudstone and dolomite set in a brown, calcareous sandy mudstone matrix. Snakes Bight Formation, unnamed brook overlooking Snakes Bight.

Plate 7: Large fragment of laminated mudstone and dolomite (lithofacies A) in intraformational mixtite, Snakes Bight Formation, unnamed brook near Snakes Bight.

Plate 8: Flat-lying synsedimentary fold deforming sandstone bed within interbedded sandstones and shales of lithofacies B of the Snakes Bights Formation. The strata lie just beneath a thick sequence of lithofacies C and B sandstones. Locality same as in Plates 6 and 7.

Interpretation of lithofacies E: The mixtites are interpreted as deposits of incoherent slides. They were produced by mass movements of previously deposited sediments and, in this regard, are similar to the chaotic deposits of flysch and lacustrine basins (McBride, 1962, 1970; Morris, 1971, 1974; Corbett, 1973; Walker and Mutti, 1973; Ludlam, 1974; Walker, 1978; Link and Osborne, 1978). Their presence suggests that unstable conditions existed within the basin. Failure was probably triggered by earthquakes, violent storms or overloading (Dott, 1963).

Several kinds of deposit are observed: (a) thick, chaotic mixtites with large clasts, (b) thick, ungraded mixtites with small clasts and (c) thinner, graded, mixtites with small clasts grading into shales and interbedded with turbidites. The presence of all three types suggests that together they originally formed a progressive sequence which reflects the relative distance of transportation. A short distance of movement (Morris, 1974; Walker, 1978) and rapid "freezing" of the slide due to decrease in shear and/or void ratio (Crowell, 1957) produced mixtites with large clasts in which bedding was locally preserved. With increasing distance of movement, shearing and mixing caused disintegration, aided by incorporation of additional water. Fragments were reduced in size to form mixtites of types b & c similar to subaqueous mudflows (Morris, 1971) and debris flows (Middleton and Hampton, 1973, 1976). The thinner mixtites that grade up into shales may have been deposited from flows that evolved into turbidity currents (Hampton, 1972).

(F) CARBONATE LITHOFACIES

Description of lithofacies F: Dolostones, ferruginous and silty dololutites, dolomitic concretions and calcareous siltstones, calcisiltites and sandy limestones comprise lithofacies F. The lithofacies appears volumetrically to be a minor part of the succession. By virtue of its intimate intercalation and interlamination with mudstone, no estimate of its percentage contribution to the formation is made.

Silty ferruginous dololutites occur as laminae and beds 1-3 cm thick in lithofacies A mudstones. The laminae, which are composed of fine microcrystalline and fibrous dolomite, are delicate, undulose and wrinkled. The 1-3 cm beds are structureless or laminated and are bounded by flat bedding planes. The dololutite beds are characterized by a clotted texture of ungraded microcrystalline dolomite, recrystallized in patches to slightly coarser dolomite. Carbonaceous stringers, scattered silt grains and rhombic crystals of dolomite are also present.

Dolomite concretions occur individually or in horizons in the lower strata of the formation. They reach 60 x 20 cm in size and are massive or laminated. Radial cracking typical of septarian nodules occurs on their undersides.

Yellow weathering, finely crystalline, massive dolostones occur most frequently near the top of the formation within laminated mudstones. They are locally bioturbated by randomly oriented, straight, curved and branching tubular burrows that are filled by dolomitic mudstone from the overlying bed.

Pale gray calcareous siltstones and calcisiltites, 1-5 cm thick, are infrequent and occur as thin beds within the turbidite succession. They have sharp, planar bases and are internally structureless, grading into fine lamination and in turn black shales.

Sandy limestones, 1-5 cm thick, are uncommon. They are bounded by flat planar bedding planes and are composed of sorted, sandy, calcarenites enclosing ooliths and intraclasts, some of which are of algal origin.

Interpretation of lithofacies F: The carbonate lithofacies is a minor part of the formation. The lack of marine fossils may indicate a nonmarine (lacustrine) rather than marine origin.

The laminae and thin beds of dolomite found mostly in facies A mudstones indicate deposition in quiet water. Microcrystalline carbonate in the mudstones is suggestive of a fairly steady though variable rain of precipitate from the overlying water column. Lime- and magnesium-rich laminae or beds probably formed when clastic or organic detrital influx into the basin was at a minimum during periods of drought in the surrounding areas (Müller et al., 1972; Müller and Wagner, 1978; Schafer and Stapf, 1978). During the droughts evaporative draw-down of lake level would have concentrated ions and promoted inorganic or biogenic precipitation of carbonates.

The abundance of dolomite in the lutites and sandstones suggests that the basin waters were rich in Ca^{2+}, Mg^{2+} and HCO_3^-. Aragonite or magnesium calcite are precipitated in modern, oligomictic or meromictic lakes during times of low water, high evaporation and a stable thermocline (Müller et al., 1972; Hubert et al., 1976). Dolomite and protodolomite form diagenetically after the precipitation of aragonite and high Mg - calcite (Müller et al., 1972). The latter minerals are known to be the primary precipitates of deeper water lakes (Müller et al., 1972; Schafer and Stapf, 1978). Patchy recrystallization of dolomite and the growth of dolomite rhombs in the rare limestones of the formation may indicate that the carbonate laminae were deposited either as calcite (Belt et al., 1967) or as high Mg - calcite. Such an origin has been postulated for the ferroan dolomites in the black mudstones of the Triassic East Berlin Formation, Connecticut (Hubert et al., 1976).

The fine intraclastic limestones and sandy calcarenites of the formation were probably deposited by turbidity currents, as they are intimately associated with turbidite deposits. A turbidite origin is not excluded for the graded calcarenites, even though its constituent allochems indicate a shallow water origin. Cline (1970) has shown, for example, that detritus formed in shallow water is commonly found as exotic clasts in turbidite sequences.

Paleocurrents in the Snakes Bight Formation

Sole marks, including flute and groove casts, provide paleocurrent information. The data were collected in an unsystematic fashion from scattered locations in the Anguille Mountains (Figure 7). For the purposes of presentation data are grouped into two areas, namely localities near Snakes Bight and those to the northwest of the Snakes Bight fault.

Southwestward to westward paleoflow dominates in the type section and in the area near Snakes Bight, although some paleocurrent indicators suggest local northwest paleoflow. At Cape Anguille some flute casts have a northnortheast vector of flow. Southerly paleoflow was recorded from beds at the top of the Snakes Bight Formation near the Cape Anguille lighthouse.

The main vectors probably relate to a northeasterly trending basin axis. This inference is supported by consistently oriented northeast trending sedimentary dikes and by the axes of slump folds. An overall northwestward directed fan-shaped distribution for all flutes (Figure 7) suggests the source of the sandstones lay to the southeast.

Age and correlative deposits of the Snakes Bight Formation

The Snakes Bight Formation has been correlated with the Strathlorne Member/formation of Cape Breton (Baird and Cote, 1964; Belt, 1969). It also compares lithologically to the middle argillaceous member of the Horton Bluff Formation (Bell, 1960; Hesse and Reading, 1978) in Nova Scotia and to the rocks of the Albert Formation in New Brunswick (Greiner, 1962, 1974). The presence in the Snakes Bight Formation of some plant fragments comparable to *Aneimites acadica* Dawson which is also common in the Horton Bluff Formation (Bell, 1960), strengthens this conclusion.

Depositional environment of the Snakes Bight Formation

The Snakes Bight Formation is interpreted as a lacustrine deposit as was first suggested by Baird and Cote (1964) and Belt (1968a, 1969). A model was not developed by those workers, however, and their interpretation leaned heavily on the lacustrine origin of time-equivalent strata in Nova Scotia (Bell, 1960) and New Brunswick (Gussow, 1953; Greiner, 1962). However, uncertainty has remained as to whether the Snakes Bight Formation could be marine rather than lacustrine. For example, the classical turbidite deposits of the formation resemble those in the marine Carboniferous of the Ouachita fold belt (Morris, 1974), the Variscan fold belt of southwest England (personal observation) and the Carboniferous of northern England (Walker 1966a, 1978). More importantly, the Snakes Bight Formation to date has not yielded nonmarine vertebrates that are common in the time-equivalent Horton Bluff and Albert Formations of Nova Scotia and New Brunswick (Bell, 1960; Carroll et al., 1972; Hesse and Reading, 1978). These two formations also abound in shallow-water and subaerial indicators, both of which occur only rarely near the top of the Snakes Bight Formation. These facts altogether indicate that a marine model could be a viable alternative to a lacustrine one. The lack of a nonmarine vertebrate fauna and other shallowlacustrine features may be accounted for, however, if a relatively deep lake is postulated. The lack of marine fossils in any lithology, but particularly in the carbonates of both the Snakes Bight and overlying Friars Cove Formations, and the presence of plant fossils, provide strong support for a lacustrine environment. Many studies of modern and ancient lacustrine

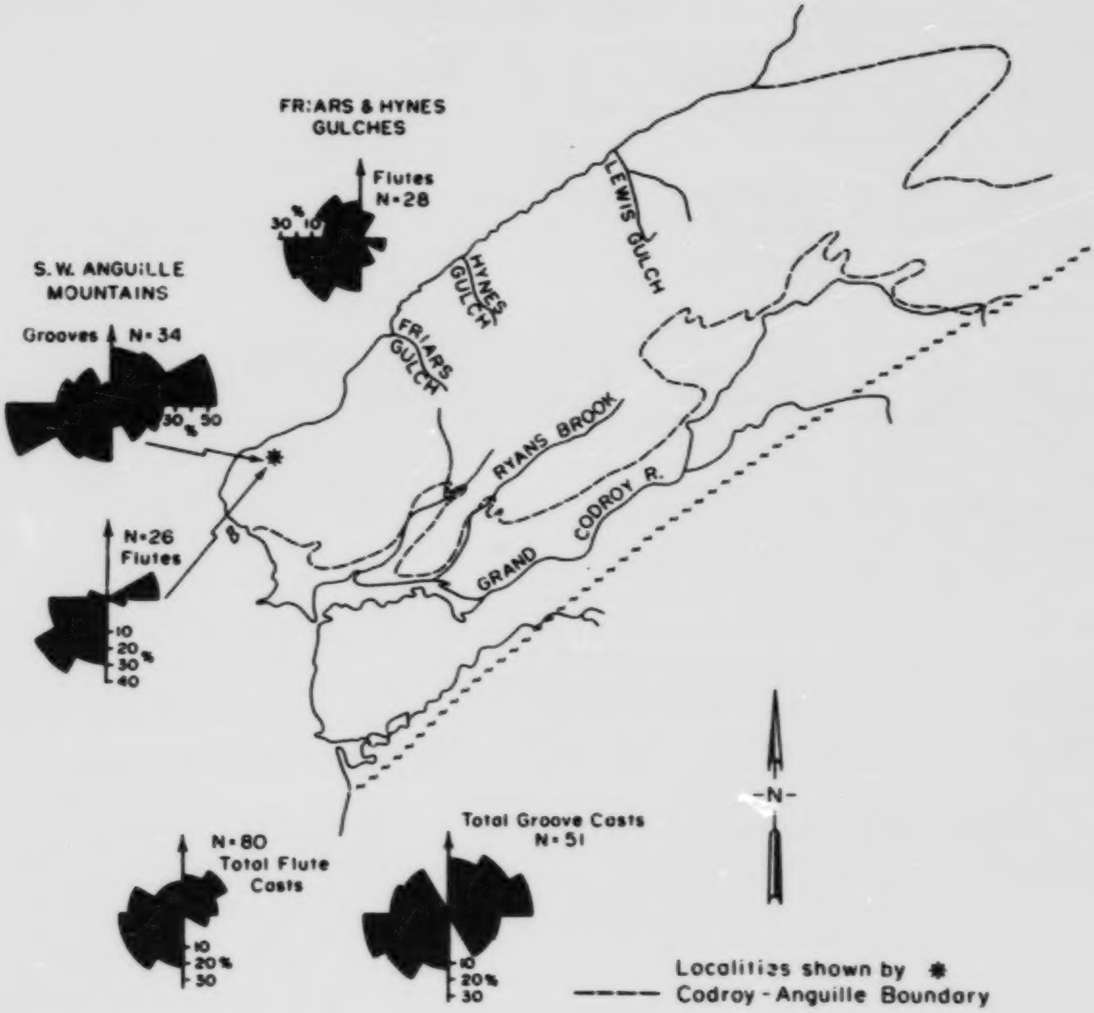

FRIARS & HYNES GULCHES
Flutes N=28
30 % 10
S.W. ANGUILLE MOUNTAINS
Grooves N=34
30 % 50
N=26 Flutes
10 20 % 30 40
LEWIS GULCH
HYNES GULCH
FRIARS GULCH
RYANS BROOK
GRAND CODROY R.
N=80 Total Flute Casts
10 20 % 30
Total Groove Casts N=51
10 20 % 30
-N-
Localities shown by *
Codroy - Anguille Boundary

Figure 7: Paleocurrent distributions in the Snakes Bight Formation.

deposits have shown that turbidity current deposits contribute substantially to the infill of deep lakes (Houbolt and Jonker, 1968; Dineley and Williams, 1968; Normark and Dickson, 1976a and b; Lambert et al., 1976; Sturm and Matter, 1978; Link and Osborne, 1978). Consequently, a lacustrine model for the Snakes Bight Formation is favoured.

The Snakes Bight Formation is interpreted to have formed in a deep, perennial lake which was infilled by mudstones, silty and sandy turbidites and shales, intraformational slide deposits and thick sequences of deltaic sandstones.

The lake was probably a narrow, northeast trending body of water that formed in a narrow graben. The lake and the graben were bounded by the Long Range fault and an upland to the southeast, and an unidentified fault and an upland to the northwest in the area of St. George's Bay. Uplift of the Long Range Mountain area in the Devonian was suggested by Brown (1977) to explain pebbles of Long Range gneiss in the Windsor Point Group, itself deposited along the Cape Ray fault. Continued uplift of the southeastern upland during the Early Carboniferous is supported by plutonic, volcanic and metamorphic detritus in sandstones of the Kennels Brook and Snakes Bight Formations. The absence of Snakes Bight strata in the Flat Bay anticline restricts the lake to the axis of the subbasin so that (when corrected for shortening of strata by deformation) it was at most 30 km wide. A minimum length of 45 km is suggested by present outcrop distribution. However, the lake may have extended at least a further 30 km to the northeast if the Snakes Bight Formation continues beneath the northeastern closure of the Anguille anticline to subcrop beneath the Barachois synclinorium. Here it would be bounded by basement at Journois Brook and Steel Mountain and would, by necessity, decrease in width to 19 km. Belt (personal communication, 1981), however, has suggested the Anguille formations are absent from the northeast of the subbasin and the present rock distribution of the group reflects the original extent of the lake deposits (see Summary and Geologic History of the Anguille Group for discussion).

The widespread distribution of finely laminated, black pyritiferous and carbonaceous mudstones suggests quiet, stagnant, anoxygenic, deepwater sedimentation below the thermocline of a stratified, meromictic or oligomictic lake. Widespread and steady precipitation of carbonate occurred in the lake with short and long periods of high precipitation giving carbonate laminae and thin beds respectively. The carbonate strata probably reflect short to prolonged episodes of net evaporation (Müller et al., 1972; Hubert et al., 1976) at which time lake level was lowered, clastic input was at a minimum and ions were concentrated. A semiarid climate probably provided such conditions. This is supported by $10^{o}-20^{o}$ paleolatitudes postulated from paleomagnetic studies of the Carboniferous rocks of Maritime Canada (Roy, 1973; Smith et al., 1973; Irving, 1977).

This graben-bound Snakes Bight lake may be similar to the lakes of the southern end of the African rift valley (e.g. Lake Tanganyika), which exist in a semi arid savannah climate. There, lake level fluctuations of up to 12 m have been documented (Livingston, 1965; Degens et al., 1971; Ojany and Ogenda, 1973). Lack of evidence for subaerial exposure in the deposits means that the lake was deep enough to withstand intensive drought and drastic reductions of water levels. Absence of sulphate evaporites suggests the lake was rarely a closed system and was probably never hypersaline during its lifetime. It should be noted that gypsum crystals can be reduced by bacteria, as for example occurs in the present waters of the Dead Sea (Neev and Emery, 1967)and hence may not be present in bottom sediments.

Laminated mudstones of lithofacies A were laid down over distal portions of the lake basin and along its flanks (Houbolt and Jonker, 1968; Ludlam, 1974; Sturm and Matter, 1978). Mud and fine silt was brought to the lake by riverborne inter- and over-flows and were circulated throughout the lake above the thermocline to settle out slowly as finely laminated 'varve-like' muds. Laminae and thin, laminated flat beds of coarser grained silt and sand in the muds were likely distal turbidites laid down mostly by low density underflows. Such underflows are known to be the common style of discharge of rivers in flood, as documented by Sturm and Matter (1978) for Lake Brienz, Switzerland. Temporary disturbance of the thermocline by wind storms (Beadle, 1974), cooling of the lake, major slope failures or renewal of high inflow (Hsü and Kelts, 1978) produced thicker deposits of silty mudstone in the fine units.

For the most part, the lake was filled by sandy turbidites and by sands of prograding deltas (Lithofacies B and C). The turbidites dominate the lower 300-500 m of the succession in the type section and in the southwest part of the Anguille Mountains. Southwestward directed paleoflow, southwestward fining of sandstones and the apparent upward coarsening of the succession from silty to sandy flysch support the deposition of a southwestward prograding prism of turbidites along the deep axial zone of the subbasin. Slump folds and sandstone dikes support a northeast trend to the subbasin and sufficient slopes (<5°, Lewis, 1971) to initiate major slope failures and production of intraformational mixtites (Lithofacies E). The variety of clast types in the mixtites suggest mass movement of basin-flank muds (Ludlam, 1974), bedded turbidite deposits, parts of sublacustrine fans (Houbolt and Jonker, 1968; Link and Osborne, 1978) and deltaic deposits (Normark and Dickson, 1976b; Link and Osborne, 1978; Sturm and Matter, 1978).

Sediment for the turbidite succession was provided by a major river, or rivers, that probably entered the lake in the northeast. Minor paleocurrent vectors directed towards the northwest suggest that sediment also entered the lake along its southeast margin.

Coarse sediment reached the axis of the deep lake in turbidity currents and likely travelled considerable distances (Gould, 1951, 1960; Houbolt and Jonker, 1968; Normark and Dickson, 1976a and b; Lambert et al., 1976; Sturm and Matter, 1978). The turbidites were probably generated by the following mechanisms: (1) formation of a turbid layer of suspended sediment, several metres thick, on the upper slopes of the delta (Normark and Dickson, 1976a and b) as a result of wave agitation; (2) failure and downslope movement of delta deposits because of slope overloading, earth tremors or severe storms (Dott, 1963), particularly when lake levels were lower (Degens et al., 1971; Kelts and Briegel, 1971; Ludlam, 1974; Normark, 1974); and (3) high density underflows that resulted from exceptional discharge of flood-swollen rivers into the lake (Lambert et al., 1976; Sturm and Matter, 1978). The underflows passed across the deltas along channels (cf. Houbolt and Jonker, 1968; Forstner et al., 1968; Lambert et al., 1976; Sturm and Matter, 1978) and deposited thick AE and ABE turbidites at the foot of the delta.

Channels with widths of several hundred metres and depths of more than 10 m have been measured in modern lakes and are known from seismic and bathymetric studies to shift position, with abandoned channels later filled by sediment (Hsü and Kelts, 1978). The thickest turbidites are commonly laid down near the foot of the delta where modern deposits can be up to 1.5 m thick (Sturm and Matter, 1978). The thickest turbidites in alpine lakes are correlated with catastrophic river floods (Sturm and Matter, 1978) which occur once or twice a century and carry a volume of sediment many times greater than the average discharge of normal floods. Consequently, the succession consists of thick sands separated by intervals of laminated, 'varve-like' muds and thin bedded, laminated, silty and fine sandy beds that were generated by low density underflows of rivers in seasonal flood.

The thickness and regular bedded nature of the turbidite succession in the Snakes Bight Formation, however, suggests that the turbidite-generating events supplied density deposits at frequent, regular intervals to the axis of the deep lake. This may reflect flashfloods over source areas at intervals of a few years or tens of years moving large volumes of detritus, as is common in semiarid climatic areas (Leopold et al., 1964; Baker, 1977). Inadequate vegetation cover in the source areas would tend to enhance the sudden catastrophic effect of these violent rainstorms when precipitation and flooding may be many times normal and slope erosion increased substantially (Leopold et al., 1964; Karcz, 1972; Baker, 1977). Consequently, sand- and mud-size detritus was likely swept from hillsides and carried by steep-gradient streams directly to the lake.

A lake with steep lateral flanks is envisioned. This concept is in keeping with the volume of turbidites and slide deposits in the lower succession. Deltas probably formed at the basin margins but were affected by frequent resedimentation of the delta front sands to deeper water. Sublacustrine fans are known to form in the deep waters of lakes in front of deltas, and have been documented in modern (Houbolt and Jonker, 1968; Normark and Dickson, 1976a) and ancient lakes (Link and Osborne, 1978). The presence of coarsening-upward sequences of turbidites (Walker, 1978) and the presence of major scour surfaces overlain by thick bedded turbidite sandstones and intraformational mixtites suggest that these rocks were deposited as sublacustrine fans in the deep axial zone of the Snakes Bight lake. The scours may represent episodes of major erosion accompanying influx of very large turbidity currents, with each scour overlain by the lobe of a fan. Overlapping of scour-based turbidite bundles might imply that the locus of deposition was linked to repositioning of delta channels.

Sediments that can be interpreted as delta deposits laterally equivalent to the lower turbidite succession have not been found to date. Nevertheless, the deeper parts of the axial zone of the lake were probably infilled by the time that coarsening-upward sequences of mudstones and sandstones were laid down in the upper half of the formation. These sequences of black, laminated mudstones interbedded with thin siltstones and sandstones and capped by thick-bedded sandstones are interpreted as the subaqueous deposits of prograding sandy deltas, that were laid down in the shallower, yet still stratified, lake. Northward paleoflow in some of the coarsening-upward sequences suggests that the deltas were associated with rivers entering the lake from its southeast margin.

Once the lake had shallowed sufficiently, the thermocline was destroyed more frequently. Organic activity and deposition of gray shales occurred in shallower waters as circulation and oxygen content improved. Thick, delta-distributary sand deposits prograded southwestward at the northeast end of the lake forming coarsening-upward sequences, with the first indications of subaerial (lithofacies A) and fluvial processes (lithofacies C). Dolostone beds formed during prolonged dry periods (Müller et al., 1972; Schafer and Stapf, 1978) in the shallow water. At the southwest end of the lake, black to gray shales and thin turbidites (lithofacies D) were overlain by the basal debris flows and sandy turbidites of the Friars Cove Formation. Deeper water conditions might have prevailed there somewhat longer.

Although information is still very preliminary, the depth of the lake possibly exceeded 100 m, to allow sufficient slope and depth for deposition of the thick turbidite sequence. A deep, large lake would also readily maintain a stratified water column. This fact would inhibit the lake waters from becoming hypersaline during prolonged periods of drought. Active basin subsidence and adequate fresh-water inflow could maintain lake depth, even if the rate of sedimentation was high. Gradual shallowing of the Snakes Bight lake suggests that subsidence possibly decreased, at least temporarily, toward the end of its history. A lake of the size and depth envisaged would thus remain a major geomorphic feature for perhaps hundreds of thousands of years. Deep water sedimentation rates of up to 6 m per 1,000 years occur in some alpine lakes, e.g. Lake Constance (Müller and Gees, 1970; Reineck and Singh, 1975), whilst deep lakes of the African rift valley have rates of 30 cm to 5 m per 1,000 years (Müller and Wagner, 1978). Postcompaction thickness of the laminated lacustrine shales of the Triassic East Berlin Formation gave a rate of 35 to 45 cm/1,000 years (Hubert et al., 1976). Lithofacies A mudstones, 180 m thick, occur in 22 units each 50 cm to 27 m thick in the type section of the Snakes Bight Formation. Allowing a slightly higher postcompaction sedimentation rate of 50 cm per 1,000 years for their deposition, a time duration of at least 360,000 years is possible for the lake. Over this interval, individual mudstone units may have taken between 1,000 and 53,000 years to be laid down.

Friars Cove Formation

Definition and distribution

The Friars Cove Formation is a newly proposed name for a sequence of gray sandstones, conglomerates and shales with minor carbonates and redbeds that conformably overlies the Snakes Bight Formation. It was previously assigned to the lower gray sandstone sequence of the Seacliffs Formation (Baird and Cote, 1964). In the northern half of the Anguille Mountains the Friars Cove Formation underlies redbeds of the Spout Falls Formation and here it comprises the third of the four formations in the Anguille Group. South of the "round valley", however, Spout Falls redbeds pinch out into a few thin units so that the Friars Cove Formation forms the uppermost unit of the Anguille Group, overlain by the basal limestones of the Codroy Group.

The formation is named after Friars Cove on the northwest coast of the Anguille Mountains. The type section (Figure 8 on foldout sheet A), located on the gulch draining into the cove, begins 0.7 km upstream and continues to the shore where the upper contact occurs. Well exposed sections occur in many adjacent valleys, on Grand Daddy's Brook, on Brooms Brook and its tributaries, and on Codroy Island. The formation has been mapped throughout the Anguille Mountains.

The lower contact of the Friars Cove Formation is placed at the base of a widely distributed conglomerate sequence. It is conformable with the underlying Snakes Bight Formation although at Cape Anguille significant erosion occurred beneath the conglomerates (Plate 9). The upper contact with the overlying Spout Falls Formation is gradational. It is placed above the last thick unit of interbedded gray sandstones and shales at the base of the first thick (>1 m) red sandstone unit interbedded with green-gray sandstones.

Gray beds similar to the Friars Cove strata appear to overlie redbeds of the Spout Falls Formation on the southeast side of Bald Mouutain and along the north branch of the Codroy River near the Long Range fault. The gray beds are

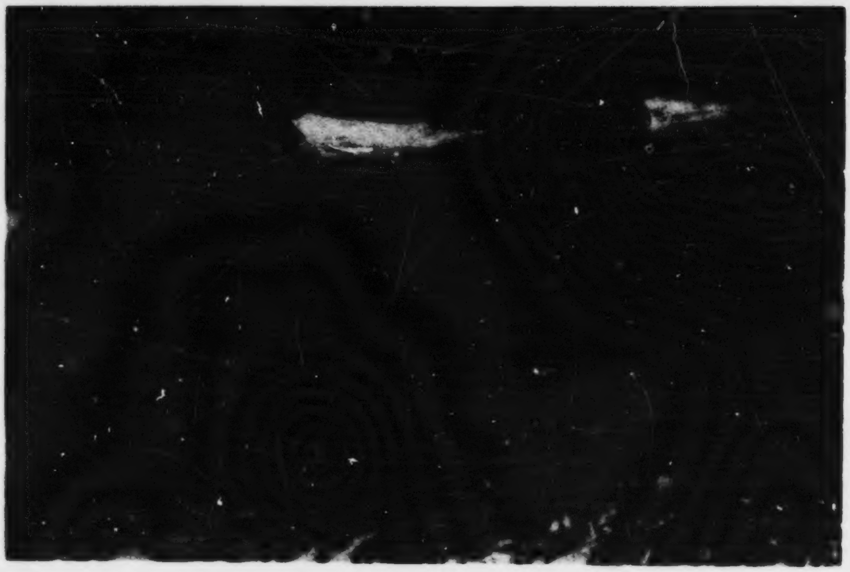


Plate 9: Thick, chaotic conglomerate beds at the base of the Friars Cove Formation. The conglomerates overlie an erosion surface that crosscuts underlying thin bedded sandstones, siltstones and shales of the Snakes Bight Formation; contact is dashed. Fish huts, near Cape Anguille lighthouse.

here included in the Spout Falls Formation on the accompanying geologic map. The relationship is believed to reflect the interfingering of the two formations in the middle of the Anguille Mountains. Alternatively, the gray beds may have been uplifted into their present position along an undetected fault to the northwest (Knight and Fong, 1975).

Thickness

The Friars Cove Formation is approximately 500 m thick in the vicinity of the type section. It is calculated to thicken southeast of the Snakes Bight fault to 690 m near Codroy and 1300 m in the northeast Anguille Mountains. Baird and Cote (1964) estimated 840 m in the area of Grand Daddy's and Brooms Brooks.

General lithology

The Friars Cove Formation consists predominantly of buff to brown weathering, gray, calcareous, arkosic and quartzose sandstones, together with some conglomerates, gray shales and minor redbeds and carbonates.

The formation begins with a widespread, 2 to 32 m thick basal sequence of interbedded conglomerates and sandstones (Figure 9). Near Friars Gulch (Figure 8) and the "round valley", they conformably overlie thick bedded sandstones (lithofacies C) of the Snakes Bight Formation. At Cape Anguille, however, the conglomerates and sandstones (Figure 10) lie upon the locally eroded, thinly bedded sandstone-shale lithofacies of the Snakes Bight Formation.

Pebbles and locally boulders ranging from a few centimetres to more than a metre in size occur in the conglomerates. They are composed of white quartz, pink and gray granites, foliated porphyritic granites, brown to red silicic volcanics, white sedimentary quartzites, gray limestone, dolomite, dolostones and chert. The largest boulders consist of granite and quartzite and have been measured up to 130 x 89 x 72 cm in size. The quartzites, carbonate and chert are clearly derived from the Cambro-Ordovician platformal succession that lies north of the subbasin. Cambro-

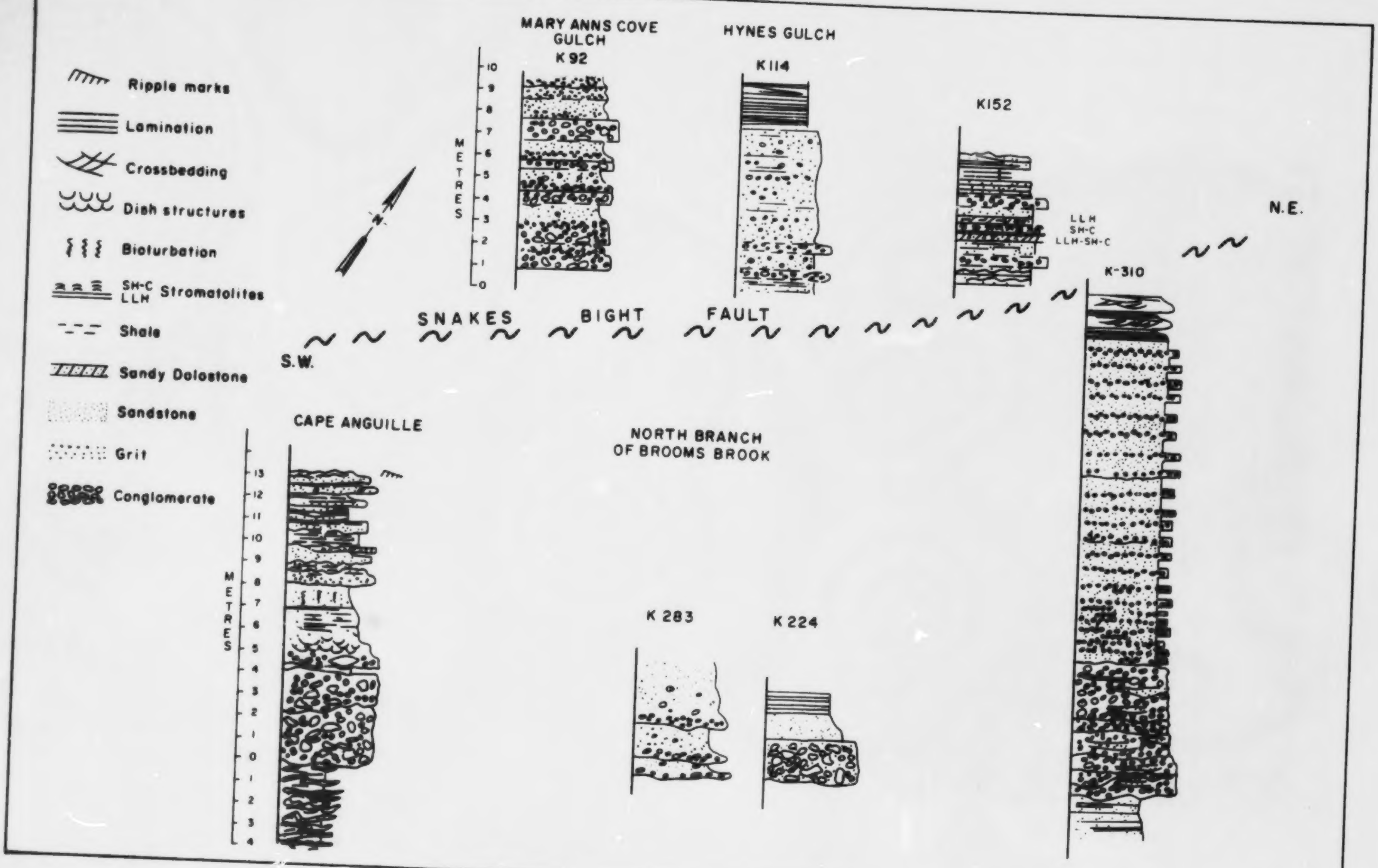

Ripple marks
Lamination
Crossbedding
Dish structures
Bioturbation
SH-C LLH Stromatolites
Shale
Sandy Dolostone
Sandstone
Grit
Conglomerate
N
MARY ANNS COVE GULCH
K 92
METRES
10
9
8
7
6
5
4
3
2
1
0
HYNES GULCH
K 114
K152
LLH
SH-C
LLH-SH-C
N.E.
K-310
S.W.
SNAKES BIGHT FAULT
CAPE ANGUILLE
METRES
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
NORTH BRANCH OF BROOMS BROOK
K 283
K 224

Figure 9: Sections measured through conglomerate - sandstone lithofacies at base of Friars Cove Formation.

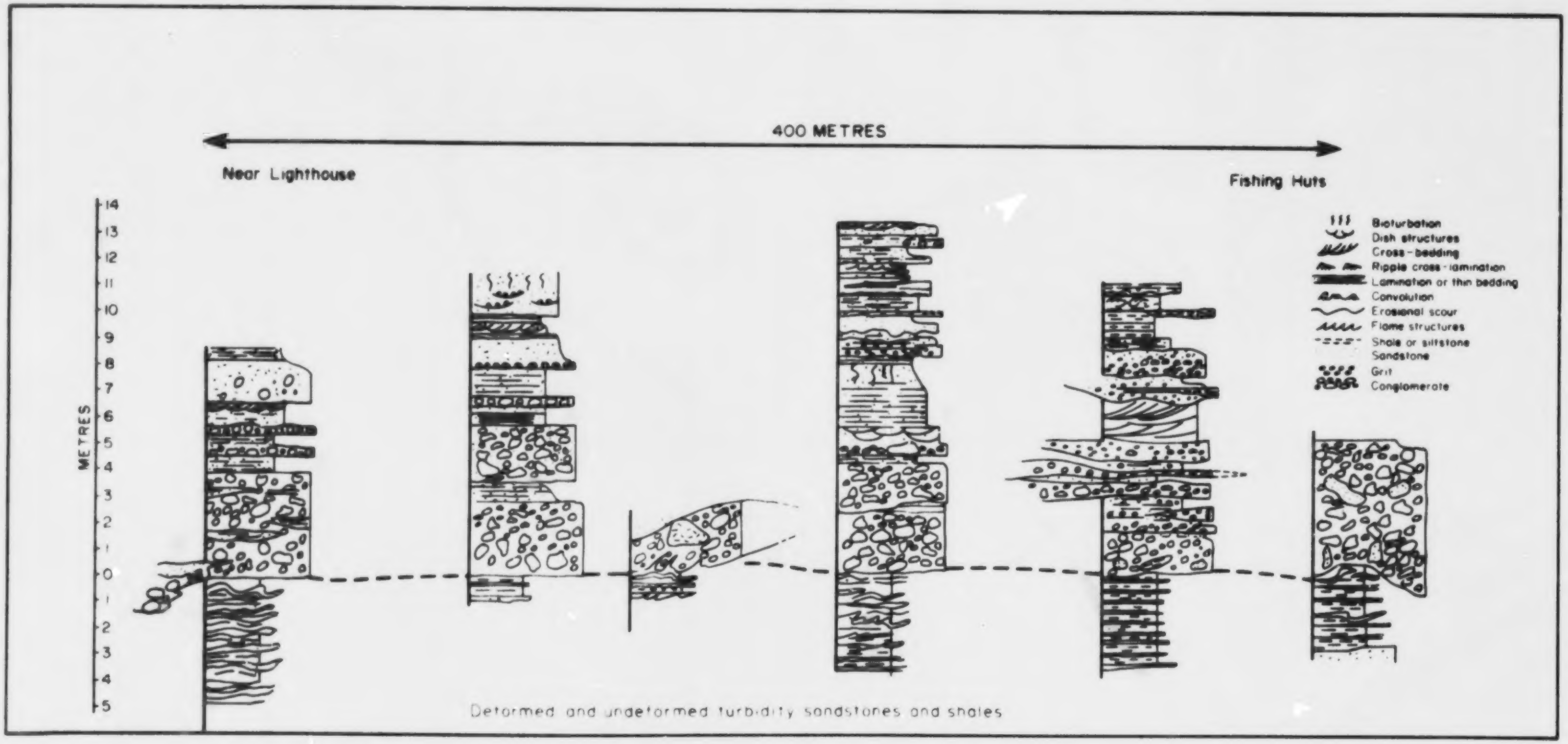

400 METRES
Near Lighthouse
Fishing Huts
METRES
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
Bioturbation
Dish structures
Cross-bedding
Ripple cross-lamination
Lamination or thin bedding
Convolution
Erosional scour
Flame structures
Shale or siltstone
Sandstone
Grit
Conglomerate
Deformed and undeformed turbidity sandstones and shales

Figure 10: Detailed sections through basal conglomerates of the Friars Cove Formation at Cape Anguille.

Ordovician clasts are particularly abundant at Cape Anguille and Lewis Gulch (Cote, 1964) as are pebbles of gneiss, diabase and ultramafic rock and green argillite. Most of these clasts are absent northeast of the "round valley" where the pebble suite is dominated by silicic volcanic and acid plutonic rocks. Granitic and other large clasts are almost always angular. Limestone and quartzite pebbles possess high sphericity and roundness.

Above the basal member, the succession varies in lithological composition from north to south along the Anguille Mountains. In the north the first 180 m of the succession is dominated by thick, planar stratified and crossbedded, medium to very coarse sandstones containing minor conglomerates and separated by thin shales. Thick units of gray to locally black shales, rich in mudcracks and plant debris and containing thin sandstones, compose the middle 118 m of the formation. The Friars Cove Formation is then completed by 180 m of crossbedded and planar laminated, gray sandstones. These rocks locally fine upward and are colored red in several units. Gray shales are thin. Rare stromatolitic dolomites occur in the basal conglomerate and in the overlying succession.

In the south of the Anguille Mountains, the succession above the basal member is dominated by thick units of either thick bedded and massive, or thinly stratified and crossbedded, gray sandstones separated by subordinate gray shales. The gray, fluviatile succession is generally monotonous, but multilithological sections also occur, especially on Codroy Island, Grand Daddy's Brook and in small, tributary brooks of Brooms Brook. Ripple-bedded quartzose sandstones, thinly bedded 'turbidite-like sandstones' and gray shales join the thick gray sandstones in these multicomponent sections. Crawling trails and burrows occur with ripple-marked sandstones and shales on Codroy Island. Evidence of dessication is found in some of the lithofacies. Arkosic grits and small pebble conglomerates, rich in fresh pink feldspar and yellow limonitic clasts, are locally present and minor redbeds occur most commonly throughout the top 310 m of the formation.

Seven major lithofacies are defined in the Friars Cove Formation and are found both in the type section and in exposures elsewhere throughout the map area. They are (A) conglomerate - pebbly sandstone lithofacies, (B) thick bedded sandstone lithofacies, (C) rippled sandstone lithofacies, (D) shale - sandstone lithofacies, (E) red sandstone and pebbly arkose lithofacies, (F) carbonate lithofacies and (G) well sorted, sandstone-siltstone lithofacies.

(A) Conglomerate - pebbly sandstone lithofacies

Description of lithofacies A: This facies, which marks the base of the formation at Cape Anguille and northeast of the "round valley", is composed of pebble to boulder conglomerates, pebbly sandstones, and calcareous, medium to very coarse grained sandstones (Figure 9). It contributes less than 2% of the strata in the formation.

Two associations occur. The first association of ungraded and graded conglomerates and thick sandstones is exposed at Cape Anguille, along Grand Daddy's Brook and in scattered localities near Brooms Brook. The second association of lenticular bedded conglomerates and sandstones can be seen northeast of the "round valley" (K 310, Figure 9) and along Lewis Gulch, southeast of the Snakes Bight Fault. It also occurs in sandstones higher in the Friars Cove Formation northeast of Morris Gulch. These associations are discussed separately below.

At Cape Anguille, the ungraded and graded conglomerate-sandstone association consists of conglomerate beds, 1 to 5 m thick, intercalated with

Plate 10: Intercalated sandstone and conglomerate at the base of the Friars Cove Formation, near Cape Anguille lighthouse. Sandstone is thinly stratified and overlies hummocky top of conglomerate bed. It is overlain erosively by the next conglomerate which contains rip-ups of the sandstone.

1-3 m thick sandstones. The ungraded conglomerates, which overlie scoured (Plate 9) to locally planar bases, are poorly sorted, massive, matrix-supported deposits. Their irregular thickness is due to hummocky tops (Plate 10). The largest clasts seen in lithofacies A are found in the ungraded conglomerates where they lie preferentially near the top of beds (Plate 10). Large, internally bedded sandstone rip-up clasts are also observed. Sediments beneath the conglomerates are locally deformed; imbricated shale tongues protrude into the base of one conglomerate, and conglomerate dikes (Plate 11) cut underlying sandstones.

Normally and inversely graded conglomerates (Plates 12 and 13) occur in beds 15 to 150 cm thick interbedded with sandstones. These uncommon conglomerates consist of pebbles generally smaller than 15 cm in diameter.

The conglomerates of the first association are generally in sharp contact with overlying, lenticular grits and medium to very coarse sandstones. The sandstones may be graded, massive (Plate 12), crudely stratified, thin bedded or laminated (Plate 10). Many beds grade from a thin, basal, small-pebble conglomerate up into thick, laminated or massive sandstone (Plate 14). Crossbeds (Plate 15) and climbing ripple lamination occur at the top of some sandstone beds above parallel lamination with parting lineations. Climbing ripple drift of types A and B (Jopling and Walker, 1968) and associated with straight, low amplitude ripple marks, was observed in one fine grained sandstone bed. The angle of climb of the type B ripple drift increases up through the bed from 35° to 48°; type A replaces type B structure in a downcurrent direction. Lunate and sinuous, asymmetrical ripple marks, rib and furrow, and oriented plant debris are also seen on bedding surfaces.

Convolute bedding, deformation of basal bedding planes, dish structures (Stauffer, 1967) and pillar structures (Lowe, 1975) (Plate 16) occur in the thicker sandstone beds.

Plate 11: A thick, lenticular conglomerate of lithofacies A, Friars Cove Formation, crosscutting underlying sandstone and thin shale of the Snakes Bight Formation, Cape Anguille lighthouse. Boulders and large pebbles are concentrated at top of plug. A pebble dike injects underlying sandstone bed at A. Measuring stick 1 m long.

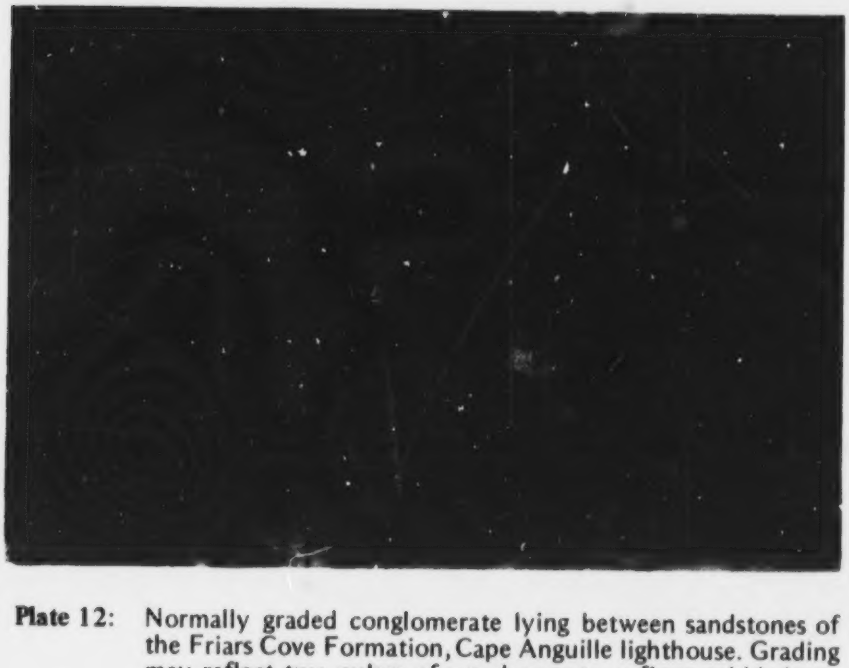


Plate 12: Normally graded conglomerate lying between sandstones of the Friars Cove Formation, Cape Anguille lighthouse. Grading may reflect two pulses of conglomerate, a finer pebble layer deposited over coarser material. Note irregular base of conglomerate with pebbles sunk into underlying sandstones. Overlying sandstone is massive. Measuring stick 1 m long.

Plate 13: Inversely graded conglomerate from basal beds of the Friars Cove Formation with erosive base into underlying sandstone bed. Hammer is 28 cm long. Cape Anguille lighthouse.

Plate 14: Graded pebbly sandstone bed, lithofacies A, Friars Cove Formation, Cape Anguille lighthouse. The bed consists of a structureless division at base overlain with sharp transition by laminated sandstone. Scale 1 *m long.*

Plate 15: Crossbedded sandstone overlying erosively graded, massive sandstone that lies above a bed of small-pebble conglomerate. Cape Anguille lighthouse.

Plate 16: Pillar structures in a sandstone of lithofacies A, Friars Cove Formation, Cape Anguille lighthouse.

Conglomerates containing lenticular sandstones, and sandstones with thin lenses of conglomerate form the second association (see K 310, Figure 9). The conglomerates have erosional bases and occur in beds 40 - 200 cm thick. They commonly show better sorting than the first association, with pebbles less than 10 cm and rarely up to 22 cm in diameter. Structureless or crudely bedded conglomerates contain lenses, up to 20 cm thick and 100 cm wide, of medium to coarse grained, gray sandstone. The conglomerates gradually become thinner up-section and, in some instances, consist of a single layer of pebbles locally thickening to 30 cm in erosional depressions within sandstones. The sandstones are 30-60 cm thick, structureless or horizontally stratified, with scattered pebbles. Crossbedded sandstones occur immediately above this association and contain some thin red units.

Interpretation of lithofacies A: The rocks of the ungraded and graded conglomerate-sandstone association at Cape Anguille are interpreted as the deposits of debris flows and thick, high-density, turbidity currents. The erosive bases and the generally structureless, unsorted, coarse, matrix-supported detritus suggest that the conglomerates were deposited by viscous mass flow processes (Middleton and Hampton, 1973, 1976; Walker, 1975b). Scouring and incorporation of partially consolidated strata occurred as the flows moved along channels. Hummocky tops, retention of bedding in sandstone rip-ups, and the preservation of shale tongues at the bases of conglomerate layers probably indicate that the beds were deposited rapidly. Deposition probably occurred when escaping pore fluid caused strength of the debris to increase above the local shear stress. A decrease in the slope of the depositional basin (and therefore a decrease in shear stress) may also have been a significant factor. The debris flows possessed sufficient matrix strength and buoyant support to maintain the largest particles toward the top of the flows during transportation.

The normally and inversely graded conglomerates, overlain by stratified sandstones, resemble the resedimented conglomerates of Walker (1975a and b). Abundant rounded pebbles of sedimentary quartzite and of carbonate imply that some clasts were previously shaped by fluvial or shallow shoreline processes. Alternatively, they may have been derived from older conglomerate strata such as the conglomerates of the Cambro-Ordovician Cow Head breccias.

The thick, massive and crudely stratified, often graded, pebbly sandstones and the thin pebble beds that grade upward into massive and laminated sandstones were probably deposited by decelerating turbidity currents (Middleton and Hampton, 1976). Rapid deposition temporily trapped fluids, which then escaped to produce dish and pillar structures (Lowe and LoPiccolo, 1974; Lowe, 1975). Types A and B ripple drift formed as the turbidity currents decelerated and fine sediment was deposited rapidly from suspension. A reduction of flow velocity or increase in suspended sediment fallout caused the angle of climb of type B ripple drift to increase. A decrease in sediment load probably caused the change from the type B to the type A structure in a downcurrent direction (Jopling and Walker, 1968).

Crossbeds formed either by the reworking of sand beds into megaripples by the tails of the turbidity currents or by later, cool, river currents that flowed beneath warmer, surface lake waters along the sublacustrine channels.

The lenticular bedded conglomerates and sandstones of the second association are characterized by their coarseness, their general lack of structure, an abundance of scouring, and a local association with thin redbeds. They were probably deposited in a shifting fluvial regime (Clifton, 1973) consisting of

Plate 17: Well bedded, planar stratified sandstone of lithofacies B, Friars Cove Formation. South branch of Brooms Brook.

braided streams (Williams and Rust, 1969; Bull, 1972). These structureless deposits were probably laid down in longitudinal bars (Doeglas, 1962; Smith, 1970; McDonald and Banerjee, 1971; Rust, 1972; Hein and Walker, 1977; Miall, 1977) and the conglomerates, one pebble thick, may be diffuse gravel sheets (Hein and Walker, 1977) deposited in the upstream reaches of sandy braided channels.

(B) THICK BEDDED SANDSTONE LITHOFACIES

Description of lithofacies B: Gray and green, calcareous, arkosic and subarkosic sandstones with subordinate pebble beds, in units up to 40 m thick, form this lithofacies. They comprise 52% of the type section and 36% of the section on Codroy Island (Cote, 1964). The sandstones show massive thick bedding, planar thin stratification, crossbedding and some lamination. Thick bedded sandstone units in the southwest of the area contain mudclasts and some pebbly horizons; the units are usually completed by cross-stratified beds. Planar stratified sandstones (Plate 17), with some pebble beds, characterize the basal 180 m of the type section of the Friars Cove Formation.

The 40-150 cm thick, graded and ungraded sandstones on Codroy Island (Sections 3 and 4, Figure 11 on foldout sheet A) are mostly structureless but may be laminated near the tops of beds (Plate 18). Flute and load casts occur on sharp bases and thin shales separate beds in some units. Crossbedded, massive grits and small-pebble conglomerates occur in channels in the middle of the units. They are composed of angular to subrounded fragments of white quartz, pink feldspar, granite, silicic volcanics, red and green quartzite, gray limestone and locally derived, yellow weathering, limonitic intraclasts. Mudcracks are found in shale partings near the top of one unit.

Trough crossbeds, 15-40 cm thick, and planar-tabular crossbeds, 40-200 cm thick, occur in the upper half of the sandstone sequences (Sections 3 and 4, Figure 11). The latter have graded, 1-8 cm, thick foresets. Rare laminated sandstones are present in the middle of units where they are characteristically

Plate 18: Lithofacies B sandstone bed, Friars Cove Formation, located at the northwest end of Codroy Island. The sandstone begins with a scoured base which is overlain by structureless and then slightly deformed, planar stratified sandstone.

Plate 19: Pebble layer lying gradationally within massive and stratified, very coarse and gritty sandstones at the base of the Friars Cove Formation, Friars Gulch. Large quartzite pebbles lie across upper boundary of pebble bed. Sequence is inverted. Note cluster of pebbles in stratified sandstone in the top left of the plate.

well sorted, contain parting lineations and are as thick as 5 m.

The planar stratified, medium to very coarse sandstones (Sections 1 and 2, Figure 11) display horizontal to slightly inclined stratification (Plate 17) defined by grain size variation such as normal grading. Parting lineations are rare, and broad, low angle, planar scours crosscut units. Small solitary and composite trough crossbeds are situated near the top of some units.

Solitary pebbles and generally clast-supported conglomerates lie within the sandstones in the Friars Gulch type section. Pebbles as large as 16 cm in diameter straddle the conglomerate-sandstone contacts (Plate 19; Section 1, Figure 11). A roughly triangular-shaped intraclast of conglomerate, 24 cm x 24 cm in size, occurs in sandstones in the same interval of the type section.

Gray, fining-upward, 2-4 m thick arkosic and micaceous sandstones occur with shales in the middle part of the type section. They commence, above a basal scour, with a mudclast lag succeeded by trough-crossbedded and some planar laminated units.

Near the top of the Friars Cove Formation, multistory sequences of gray, trough- crossstratified and planar-laminated sandstones predominate (See Figure 8, and Section 7, Figure 11). Ripple cross-lamination, plant rootlets and red coloration occur at the top of some units.

Interpretation of lithofacies B: The characteristics of lithofacies B suggest that the thick bedded sandstones were deposited in fluvial channels and as deltaic sand bodies around the margin of a lake.

The association of shallow lacustrine deposits with the thick, massive and crossbedded sandstones on Codroy Island and with the thick, planar stratified sandstones in the lower 180 m of the Friars Cove type section implies that these thick sandstones were laid down along the margins of the Snakes Bight - Friars Cove lake.

On Codroy Island, massive, thick-bedded sandstones overlain by minor laminated and, in turn, crossbedded sandstones form a vertical succession of facies units. There lithofacies B sandstones, with sharp, locally fluted bases and abundant intraclasts, resemble thick proximal turbidites (Walker, 1967). Rapid deposition of large quantities of sand was most probably affected by powerful currents (Banerjee, 1977). Interbedded shales, some of which are mudcracked, may indicate distinct depositional pulses and generally shallow water depth. This seems to suggest the presence of high density underflows discharging from a river mouth into a shallow lake. Rapid deceleration possibly occurred as the turbidity currents spread out beyond the river mouth. In other units, where shale is absent, the upward thickening of beds interspersed with some grits and conglomerates provides evidence that some of the sand bodies were prograding rapidly across the lake margin.

Above the massive, thick bedded sandstones, planar laminated sandstones with parting lineations are overlain by crossbedded deposits. These rocks seem to indicate that flow conditions changed as distributory channels were established or infilled, accompanied by a decrease in bed load and current velocities (Harms and Fahnestock, 1965; Southard, 1975). The large, planar crossbeds were probably deposited as cross-channel, transverse or linguoid bars (Cant and Walker, 1978; Smith, 1971, 1972; Collinson, 1970b) in sandy braided channels. Trough crossbeds formed within megarippled sand waves (Harms, 1975) that migrated along channels (Cant and Walker, 1978). Similar sequences of massive, thick bedded sandstones overlain by heterogeneous crossbedded sandstones have been illustrated by Kelling and George (1971) from fluvial distributary channels of the Pembroke Coalfield, South Wales. There, the massive sandstones are also interpreted as flood deposits within channels that scoured into a delta front sequence, and there they are overlain by crossbedded sandstones thought to have been deposited by migrating dunes and bars.

The planar stratified sandstones in the Friars Cove type section were deposited by traction currents which were strong enough to transport both pebbles and sand (Harms and Fahnestock, 1965) and to erode and move large rip-up clasts of partly consolidated conglomerate. The pebbles rolled along the bed, whilst medium to very coarse sand was carried in suspension (Walker, 1975a, Figure 7-3, page 140). As flow decelerated, pebbles ceased rolling and were deposited within sand beds characterized by upper flow regime plane beds (Simons et al., 1965; Harms, 1975; Southard, 1975). Where large quantities of pebbles were moved as bed load, pebble beds were formed.

The thick, planar stratified sandstones possibly formed in large, deep channels with a fairly steady flow strength (Rust, 1972; Harms, 1975; Southard, 1975). Ephemeral streams (Picard and High, 1973), which commonly

Plate 20: Interference and straight ripple-marks in thin bedded, rippled sandstones (lithofacies C, Friars Cove Formation), Codroy Island.

possess sufficient surplus energy to erode and transport large objects during flood (McKee et al., 1967; Williams, 1971), may also produce such deposits. Broad scour surfaces in the planar stratified sandstones suggest the deposits were built up by repeated influxes of sediment under similar flow conditions. This may support the latter interpretation.

Finally, sandstone deposits of the delta plain include the fining-upward sandstones within shales and multistory sandstones in the upper part of the type section of the Friars Cove Formation. The former bear the characteristics of deposits of meandering river channels (Allen, 1965a; Walker, 1979a). The latter resemble facies in the overlying Spout Falls Formation and were probably laid down by sandy braided streams.

(C) RIPPLED SANDSTONE LITHOFACIES

Description of lithofacies C: This lithofacies, 50-500 cm thick, is best developed south of the "round valley", particularly on Codroy Island (Sections 3 and 4, Figure 12 or foldout sheet A) where it forms less than 2% of the section. It begins with a sharp to locally erosive base above lithofacies B sandstones and passes gradationally upward into shales and thin sandstones. In places, a bed of crossbedded sandstone overlies the basal scour. Otherwise, lithofacies C consists of well sorted, fine, locally dolomitic, quartzose sandstone beds. These beds are arranged in 28-84 cm thick units of rippled, thin bedded sandstones (Plate 20) alternating with 15 cm beds of planar laminated sandstones with mudstone partings. Straight, sinuous, bifurcating and interfering symmetrical ripple marks cover complete bedding planes. They are characterized by 2-12 cm wavelengths, 0.25 to 1.5 cm heights and ripple indices (Tanner, 1967) of 4 to 12. Linguoid ripple marks, rib and furrow, some type A ripple drift (Jopling and Walker, 1968) and ripple cross-lamination associated with scoop-shaped scours also occur. Some ripple marks are flattened or gently rounded. Smooth and mudcracked mudstone and thin dolomite or limestone drapes fill troughs or cover rippled surfaces (Plate 21).

Plate 21: Yellow weathering dolostones covering rippled sandstone bed, Codroy Island. Location as in Plate 20.

Interpretation of lithofacies C: The well bedded and sorted, ripple-marked sandstones with locally developed basal scours and the crossbedded sandstones are interpreted as the record of shallow water sand flats formed by currents that reworked the top of facies B sandstones. Interference ripple patterns, ripple symmetry and the flattened shapes of the ripples together suggest that the ripple marks were modified by later currents or by gentle, oscillating wave activity. Mud drapes were deposited in still water, and limestone or dolomite precipitated when the shallow water covering the rippled sands became increasingly saline and alkaline due to evaporation (Liebermann, 1967; von Borch, 1976). Exposure and dessication of the sand flats was common.

(D) SHALE-SANDSTONE LITHOFACIES

Description of lithofacies D: Sequences 5 to 32 m thick, composed of shales and interbedded shales and sandstones, comprise lithofacies D (Sections 2 to 6, Figure 11). Three associations occur.

The first association occurs in the southwest of the area and lies gradationally above rippled sandstones. It begins with interbedded shales and rippled and flat-bedded sandstones gradationally below a middle section of shale. The shale section is in turn intercalated with thin sheet sandstones below lithofacies B sandstone units.

The rippled sandstones resemble those of facies C, but they are more argillaceous and display starved ripples, lenticular beds and bioturbation. Ichnofossils (Plates 22 and 23) include structureless trails and burrows and 1-2 cm wide trails decorated by an asymmetrical V-shaped ornamentation resembling chevron trails (Frey and Howard, 1970; Howard, 1972) and *Crossopodia* (Hantzschel, 1975). Mudcracks also occur locally.

The shales of the first association are 1-5 m thick, gray colored and contain paper-thin dolomite laminae and thin beds of ferruginous siltstone. The sheet sandstone beds that are interbedded with the shales at the tops

Plate 22: Burrows and chevron trails criss-cross a flat bedding plane of a silty sandstone of lithofacies D, Friars Cove Formation, west shore of Codroy Island. Large mudcracks are also present.

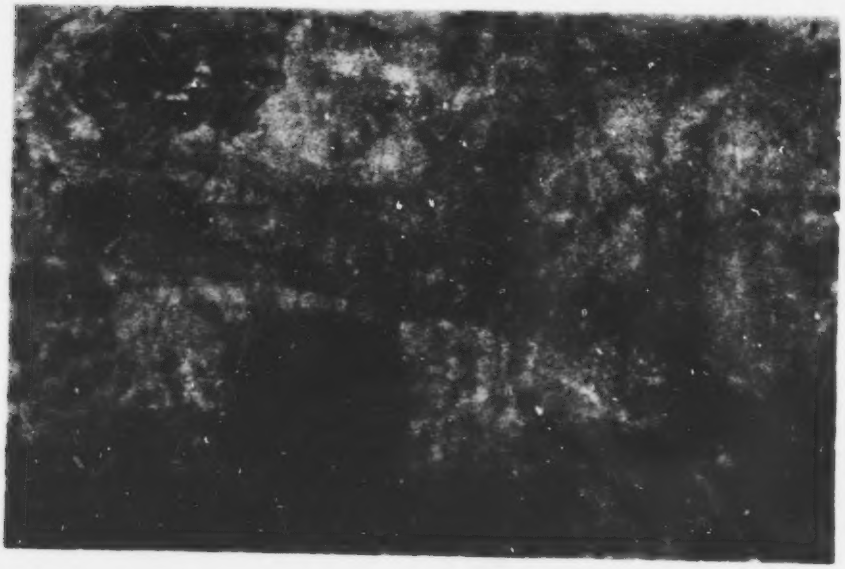


Plate 23: Close-up of chevron trail shown in Plate 22.

of the sequences are fine grained and 5-20 cm thick. They have sharp, locally fluted, bases and internally consist of a massive division with small mudchips, overlain, in general, by lamination and ripple cross-lamination. Parting lineations occur and soft sediment deformation is common.

The second association consists of gray and black shales with a variety of interbedded sandstones and has been mapped in two thick sequences northwest of the Snakes Bight Fault (Section 5 and 6, Figure 11). These strata are associated with the gray, crossbedded, fining-upward, channel sandstones of lithofacies B. Mudcracks and plant rootlets are common in some of the gray shales but are lacking in others. The black shales appear to lack mudcracks and are rich in blade-like plant fragments.

Thin, planar bedded, laminated siltstones and very fine sandstones, 1-6 cm thick, are interspersed in the shales. They become increasingly abundant close to the facies B channel sandstones, where they are sheet-like, graded deposits up to 30 cm thick, and locally 2 m thick. Mudcracked bases are common and sedimentary structures include lamination, cross-lamination and small isolated crossbeds. In contrast, sheet sands with flat, irregular to fluted bases are usually seen in association with shales lacking mudcracks.

The third association also consists of sequences of alternating shales and sheeted sandstones. They lie stratigraphically above the gray and black shale sequences toward the top of the type section and attain thicknesses of 5-24 m. Here, the association comprises sheet-like deposits of gray, arkosic and micaceous sandstones, up to 30 cm thick, that alternate with 5 - 30 cm beds of mudcracked, green shales. The medium to very fine grained sheet sandstones are normally graded. Internally they are planar stratified, laminated and ripple cross-laminated. Crossbedding (5-15 cm thick sets) is less common. Bases preserve mudcracks and the tops of some sandstone beds are red. They closely resemble some of the beds in the Spout Falls Formation.

Interpretation of lithofacies D: The shales and sandstones of the first association in lithofacies D were deposited in shallow nearshore to offshore settings in what is now the southwest of the area. Alternating shales and rippled and planar bedded sandstones, containing trace fossils and locally mudcracks, may imply shallow sublittoral to shoreline deposition. Shales lacking subaerial features but displaying dolomite laminae and thin laminated siltstones overlie these shoreline deposits. They suggest that water level rose to establish a quiet offshore setting dominated by deposition from suspension. In contradistinction, the intercalated sheet sands point to a turbidite origin. Turbidity currents presumably reached the offshore environment ahead of the prograding deltas responsible for sandstones of lithofacies B.

In the northwest and locally above thick sandstone units in the southwest (Section 2, Figure 12), the gray shales of the second association contain abundant evidence of dessication and active growth of vegetation. This suggests delta-top floodplain environments consisting of swamps and local, shallow ephemeral lakes. Anoxygenic gray and black shales without mudcracks were deposited locally in more permanent lakes.

Sheet sandstones and planar stratified sandstones periodically blanketed the floodplain muds as flood waters breached river channels. Sand sheets with turbidite-like structures were laid down in the lakes, whilst crevasse-splay sand sheets inundated the exposed muddy flood plain.

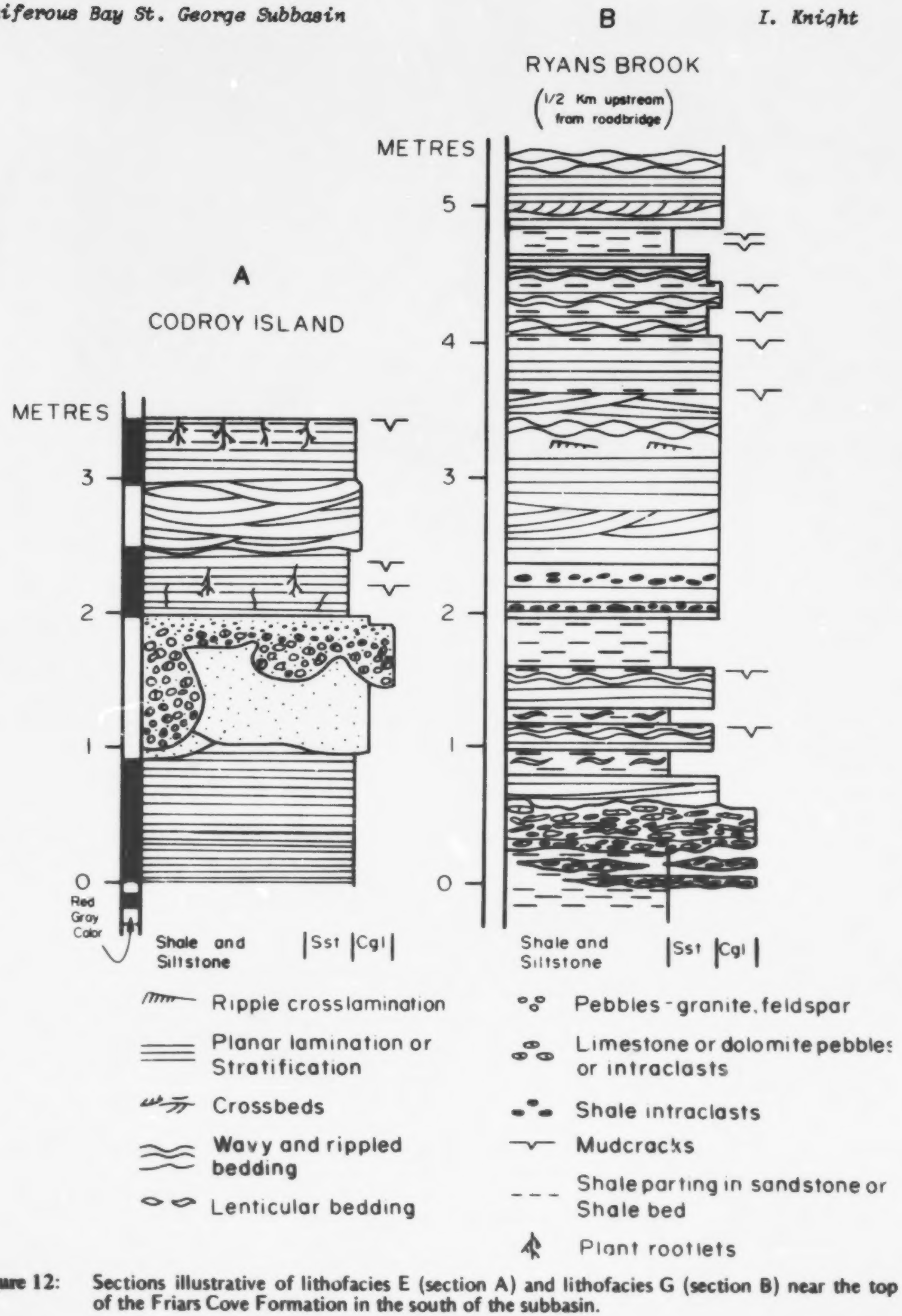

B
RYANS BROOK
(1/2 Km upstream from roadbridge)
METRES
5
4
3
2
1
0
Shale and Siltstone
Sst
Cgl
A
CODROY ISLAND
METRES
3
2
1
0
Red
Gray
Color
Shale and Siltstone
Sst
Cgl
Ripple crosslamination
Planar lamination or Stratification
Crossbeds
Wavy and rippled bedding
Lenticular bedding
Pebbles - granite, feldspar
Limestone or dolomite pebbles or intraclasts
Shale intraclasts
Mudcracks
Shale parting in sandstone or Shale bed
Plant rootlets

Figure 12: Sections illustrative of lithofacies E (section A) and lithofacies G (section B) near the top of the Friars Cove Formation in the south of the subbasin.

Plate 24: Conglomerate composed mostly of small feldspar and ferruginous pebbles crosscutting green arkosic sandstones, lithofacies E, Friars Cove Formation, west shore of Codroy Island. The erosive base of the conglomerate was subsequently deformed by loading.

The sequences of sheet sandstones in the third association of lithofacies D are intercalated with mudcracked, green shales and they are interpreted as the deposits of shallow, ephemeral streams. They compare in character and origin to deposits of lithofacies B of the Spout Falls Formation. The nonerosive bases, the sheet-like beds, the dominantly planar lamination and the thin internal stratification are all in common with ephemeral stream deposits (Frostick and Reid, 1977; Tunbridge, 1981a and b).

(E) RED SANDSTONE AND PEBBLY ARKOSE LITHOFACIES

Description of lithofacies E: Facies E is recognized only on Codroy Island, Grand Daddy's Brook and in some outcrops in the hills east of Ryans Brook. It represents only a few percent of the total Friars Cove Formation. It is composed of green to red arkosic small-pebble conglomerates, grits and very coarse and coarse sandstones lying erosively upon and overlain by micaceous, fine grained, red sandstones (Plate 24; Figure 12A).

Structureless, green, very coarse sandstones are overlain erosively by structureless conglomerate and grit in the section illustrated from Codroy Island (Figure 12A). These rocks consist of well sorted, angular pebbles of fine and medium crystalline red granites, pink feldspar, granite gneiss, brown-red rhyolite, green argillite, white quartz and yellow weathering limonitic clasts. The conglomerates are overlain by more green, coarse sandstones that contain 2 cm layers of arkosic grit and heavy mineral laminae.

The associated red sandstones are planar laminated and thin bedded below the arkosic rocks. Above the arkosic rocks, they also include some ripple drift, crossbeds, plant rootlets and shale partings with mudcracks and rain prints.

Interpretation of lithofacies E: Although there is a contrast in composition, grain size and sedimentary structures of the two lithologies of the facies, both deposits are interpreted as ephemeral stream deposits produced by flash floods of different magnitudes.

Red, thick, fine grained, micaceous sandstones were probably the characteristic deposits of the area. They illustrate planar lamination and thin bedding, ripple drift and mudcracked shale partings. These features are characteristic of shallow, sandy, ephemeral streams produced by flashfloods of moderate magnitude (Williams, 1971; Picard and High, 1973; Frostick and Reid, 1977; Tunbridge, 1981a).

The coarse grained arkoses, however, are thick bedded, generally structureless, and rest in scours. The structureless character suggests rapid deposition of highly concentrated sand and gravel flows by a number of flood pulses, each of which had sufficient energy to scour a channel which it later filled. Major, but rare, catastrophic flashfloods probably served to bring coarser sediment into the more distal parts of the ephemeral stream system (Baker, 1977; Frostick and Reid, 1977). The composition of the detritus suggests a source southeast of the Long Range fault.

(F) CARBONATE LITHOFACIES

Description of lithofacies F: This minor facies includes stromatolitic dolomites, sandy dolomites and limestones, and dolomitic or calcareous sandstones. Sandy carbonates occur mostly in the southeast of the subbasin where they are associated with rippled sandstones of lithofacies C and shales of lithofacies D. To the northwest of Snakes Bight, one occurrence of stromatolitic dolomite has been noted in the basal conglomerate-sandstone facies (Section K 152, Figure 9). Similar units are also found in a shale sequence higher in the Friars Cove Formation in an unnamed stream valley near Johnson's Gulch.

The stromatolitic dolomites occur with the sandy dolomites. They are yellow weathering, simple structures that include small heads resembling algal biscuit structures (Gebelein, 1969), broad flat heads composed of smooth laminated mat (Plate 25) and SH-C and SH-V growth forms (Logan et al., 1964) up to 10 cm in height and 7 cm wide. Loose float blocks of edgewise breccia and stromatolite are found in Grand Daddy's Brook. The associated sandy dolomites enclose intraclasts derived from the stromatolites. They are massive or poorly stratified and occur interbedded with thinly bedded, locally bioturbated, gray calcareous mudstones, 30 cm thick.

Plate 25: Laminated dolomite overlying calcareous mudstone with small algal 'biscuit' near base. Intraclastic, sandy dolomite occurs above the laminated dolomites. Lithofacies F, Friars Cove Formation, unnamed stream northeast of Hynes Gulch.

The sandy limestones occur as well sorted, planar- or cross-laminated and ripple-marked deposits. They form beds

Plate 26: Photomicrograph of Lithofacies F, Friars Cove Formation containing dolomite-coated sand grains and some carbonate grains set in a spar cement.

Plate 27: Photomicrograph of ooids, carbonate intraclasts and silt grains set in sparry cement. Intraclasts enclose ooids which were previously bound and cemented before reworking. Same locality as Plate 26.

10-15 cm thick and contain lenses of massive gray micrite. The sandy limestones are composed of clean sand grains, micrite-coated sand grains (Plate 26), ooids (Plate 27) and intraclasts of spar, micrite, calcareous algae and stromatolite. Some intraclasts enclose two or more ooids (Plate 27) and show early cementation.

Intergranular porosity, now indicated by the abundance of clear, coarse spar cement, was initially high.

Interpretation of lithofacies F: The carbonate facies was deposited locally in shallow, marginal lacustrine settings and is comparable to many modern and ancient lacustrine carbonate deposits (Fannin, 1969; Donovan, 1975; Eugster and Hardie, 1975; Link and Osborne, 1978; Schafer and Stapf, 1978). Mudstones were deposited in quiet lagoons. Stromatolites and well sorted, ripple-marked sandy carbonates formed in agitated shoal and shoreline areas. Laminated algal mats developed on mud flats which were dessicated and locally disintegrated to provide abundant intraclasts.

Carbonate is rare and apparently only dolomites are present northwest of the Snakes Bight fault. Both limestones and dolomites occur, however, in the southeast where the limestones are rich in ooids and intraclasts. This suggests that the limestones may have been formed in more open, agitated, nearshore waters, whilst the microcrystalline dolomites formed in restricted, possibly hypersaline areas only centimetres deep (von des Borch, 1976; von der Borch and Slock, 1979).

(G) WELL SORTED, SANDSTONE-SILTSTONE LITHOFACIES

Description of lithofacies G: To date, lithofacies G has only been recorded in the uppermost strata of the Friars Cove Formation in the southeast of the area where it is only a minor component. There it is composed of well sorted, buff weathering, gray or black, generally fine grained sandstones and siltstones associated with some gray shale and rare intraclastic dolomite beds (Figure 12B). The sandstones illustrate variable bed thicknesses, and shale partings are common. Internal structures include lamination, flat bedding, ripple-drift cross-lamination, crossbedding and convolution. The laminations are sorted by grain size; some are rich in heavy minerals and/or mica and many exhibit parting lineations. Mudclast-rich layers are common in the sandstones. Ripple-marks also occur, covered by either smooth or mudcracked and rain-pitted shale drapes. Some 30 cm thick, laminated, silty mudstones displaying lenticular and wavy bedding (cf. Reineck and Wunderlich, 1968) are interbedded with the sandstones.

Intraformational breccias are composed of shale, dolomite and reddened limestone intraclasts set in a shale and carbonate matrix. The breccias form lenses and beds 5 to 30 cm thick. Some beds are overlain by red, mudcracked, thin bedded siltstones and sandstones.

Interpretation of lithofacies G: The presence of intraformational dolomite breccias, rippled sandstones, well sorted laminated sandstones and mudcracked horizons suggests that facies G was also deposited in a shallow water, marginal lacustrine setting. Lake levels fluctuated frequently on local and regional scales as water rose or fell in response to storms, evaporation, river inflow and outflow, and the driving effects of onshore or offshore winds (Oomkens, 1970). The sandstones with good sorting, ripple marks and laminated bedding were deposited on sandflats and beaches during high water levels. Mudflats and carbonate flats, which were later dessicated, formed as water levels receded. Intraformational breccias were produced when the flats were reworked during the next high water stage. In some cases, however, the dessicated flats were overlain by red, fine alluvium as offlap continued.

Strikingly similar facies occur in the Triasic East Berlin Formation of Connecticut (Hubert et al., 1976), where laminated and rippled sandstones are interpreted to have formed as sands on the shores and beaches of lakes.

Paleocurrents in the Friars Cove Formation

Paleocurrent measurements of ripple marks, parting lineations, rib and furrow and a few crossbeds are shown in Figure 13.

On Codroy Island, the few crossbeds give a fan-shaped, northwestward distribution. Parting lineations in the same area also give a northwestward trend. In the Anguille Mountains, crossbeds give west and southwestward directions, whilst parting lineations trend north-south. Data is insufficient, however, to make valid conclusions.

Symmetrical ripple-marks from the rippled sandstones of lithofacies C have a prominent east-southeast to southeast crest trend and asymmetrical ripples give a north-northeast paleoflow (see also Cote, 1964, pages 254-257). These ripple-generating currents were perpendicular to those of the crossbeds and parting lineations, perhaps

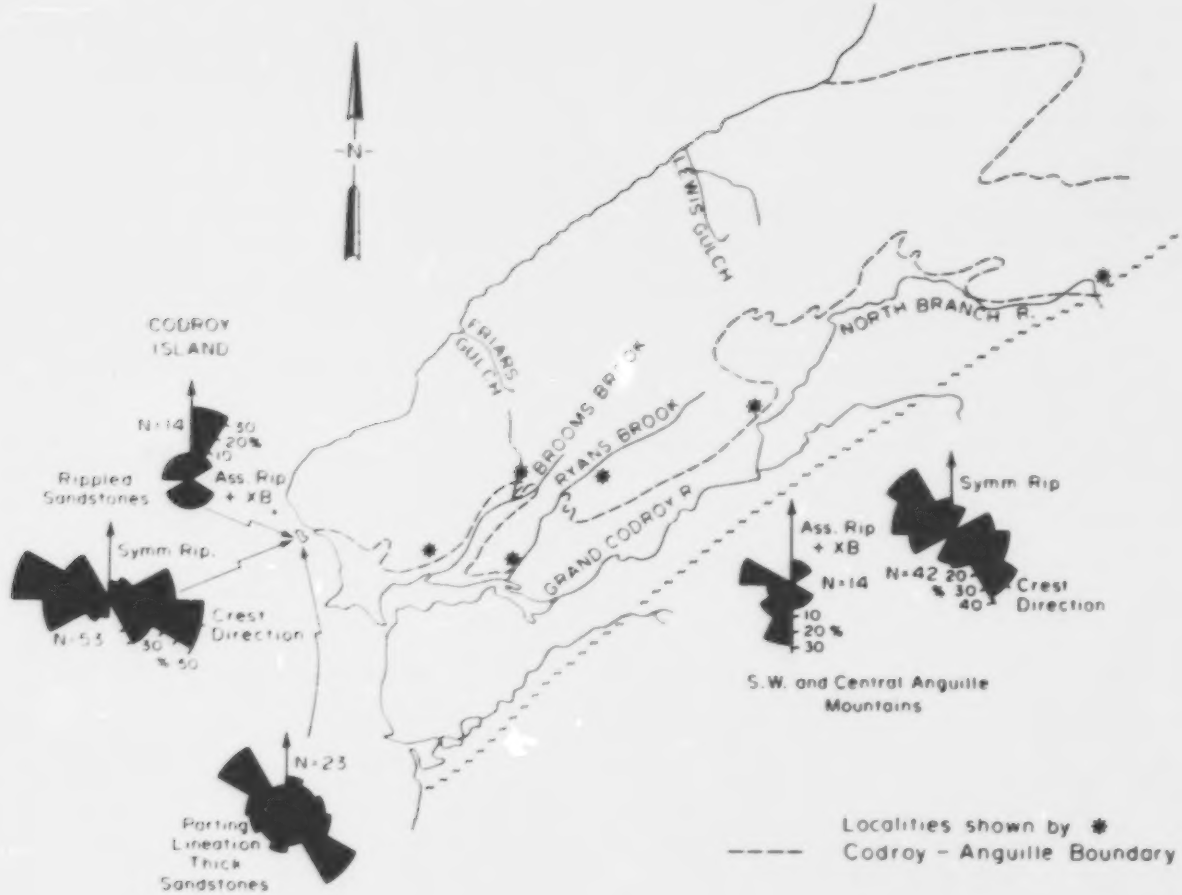

-N-
CODROY ISLAND
N=14
30
20%
10
Rippled Sandstones
Ass. Rip + XB
Symm Rip.
N=53
30
% 50
Crest Direction
N=23
Parting Lineation Thick Sandstones
LEWIS GULCH
FRIARS GULCH
BROOMS BROOK
RYANS BROOK
NORTH BRANCH R.
GRAND CODROY R.
Ass. Rip + XB
N=14
10
20 %
30
Symm Rip
N=42
20
% 30
40
Crest Direction
S.W. and Central Anguille Mountains
Localities shown by ✱
---- Codroy – Anguille Boundary

Figure 13: Paleocurrent distributions in the Friars Cove Formation.

reflecting a northeasterly prevailing wind direction.

Age and correlative deposits of the Friars Cove Formation

No paleontological data is available for the Friars Cove Formation. Samples processed for microspores failed to yield any flora (Cote, 1964; Barss, personal communication 1979). The formation was correlated with the Ainslie member/formation of Cape Breton (Cote, 1964; Baird and Cote, 1964; Belt, 1969).

Depositional environment of the Friars Cove Formation

The gray sedimentary rocks of the Friars Cove Formation were deposited dominantly in a fluvial-deltaic, shallow lacustrine setting as the final fill of the Snakes Bight lake.

A significant period of tectonic instability occurred during the development of the Friars Cove Formation and is evidenced by the nature of the basal conglomerate member, the presence of thick sandstones throughout the formation, the immature composition of the sediments (see Petrography of Siliciclastic Rocks of the Anguille Group), and the marked stratigraphic thickening both northeastward and from northwest to southeast across the Snakes Bight fault. Subsidence and uplift occurred along northeast trending faults. In particular, the Snakes Bight fault was an active growth fault along which the southeastern part of the subbasin subsided. Cambro-Ordovician platformal rocks, Taconic ophiolite massifs and underlying Precambrian crystalline rocks were uplifted to form an upland herein named the Humber Arm allochthon highlands. These highlands provided detritus to the subbasin for the first time from north of the subbasin. Granitic and silicic volcanic pebbles in conglomerates laid down in the central and southeastern parts of the Anguille Mountains seem to indicate synchronous uplift of Paleozoic volcanic and granitic rocks southeast of the Long Range fault. Uplift of these source areas maintained steep drainage gradients so that rivers swept large quantities of coarse sandy (initially conglomeratic) material into the basin. Little evidence is available to determine the climatic conditions. Dolomite laminae in the shales and the rare dolomitic and stromatolitic beds as well as sandstones that were deposited by ephemeral streams suggest a semiarid climate.

Sandy detritus, which dominates the first 180 m of the Friars Cove Formation, was probably deposited in deltas that inundated the margins of the shallow lake in which the gray shales were accumulating. Along the northwest side of the subbasin, stratified, often pebbly, sandstones were deposited in ephemeral streams at times of flash floods. These sediments built up a series of fan deltas (cf. Sneh, 1979; Wescott and Ethridge, 1980) adjacent to the Humber Arm allochthon highlands and the highlands southeast of the Long Range fault. Processes and deposits on the subaerial portions of fan deltas are essentially similar to those on modern alluvial fans (Wescott and Ethridge, 1980). Sandy sheetflood and ephemeral stream deposits would lie basinward of inner-fan debris flow or stream gravel deposits. The latter reached the axis of the subbasin only rarely. Their existence is supported, however, by the Cape Anguille conglomerates. Gravel deposits were funnelled along channels into a deeper water zone of the lake during the initial stages of fan delta construction. Lithostratigraphically, this episode marks the base of the formation. Basal conglomerates and sandstones in the center of the subbasin have a provenance to the southeast and show characteristics of braided streams. Similiar lithologies may also have occurred along the southeastern margin of the subbasin at this time.

The middle part of the Friars Cove Formation, in the area northwest of the Snakes Bight fault, is dominated by gray shales and sheet and channel sandstones. Mudcracked horizons, plant remains and the presence of thin overbank sheet sands suggest a flat lying, broad, delta flood plain spotted with ponds and small lakes. Sediment was supplied by overbank flooding and crevassing from distributary channels and is represented by the fining-upward, crossbedded sandstones of lithofacies B. Sequences of intercalated shales and sheet sands (see association 3 of lithofacies D) formed on a mud and sand flat that lay along the inner edge of the delta flood plain. In the type section area, these deposits generally overlie shales interpreted to have formed upon the delta flood plain (association 2 of lithofacies D). The repetitive bedding suggests the sands probably resulted from reworking of sandy alluvium, perhaps from an alluvial fan, by ephemeral sheetfloods. The sheetfloods were generated by flashfloods that flushed the sand onto the inner edge of the muddy delta plain. This is the process and environment suggested by Smoot (1978) for deposits of comparable interbedded shales and sheet sandstones in the Wilkins Peak Formation of the Green River Formation. Crossbedded and laminated sandstones, locally oxidized to a red color, overlie the delta plain shales and sand and mudflat deposits. Lack of fine, red, overbank deposits associated with these gray sandstones and their resemblance to the redbeds of the overlying Spout Falls Formation suggests they were deposited by sandy, braided streams. They carried sandy detritus from basin-margin alluvial fans southeastward onto the inner margin of the delta plain.

On Codroy Island, a 690 m thick, incomplete section of the Friars Cove Formation illustrates cyclothems in the lower 120 m. Each cyclothem begins with shales overlain by massive bedded and thick crossbedded sandstones that are, in turn, superseded by ripple-marked sandstones. Their presence in the southeast of the subbasin suggests that, at various times, the lake was filled by fluvially dominated, sandy deltas (Galloway, 1975). Provenance and paleocurrent data indicate that the deltas were built out into the lake along its southeast margin. The cycles point to both constructional and destructional phases. Thick bedded, massive sands were deposited by sediment-laden floods discharged from river mouths. These high density underflows (cf. Lambert, et al., 1976; Sturm and Matter, 1978) probably constructed a large lobate-shaped delta (Miall, 1979). Shale interbeds, some mudcracked, may show that sedimentation was shortlived and repetitive. This may have been caused by frequent redirection of distributary channels due to avulsion or crevassing, or by intermittent fluvial sedimentation that was primarily controlled by the semiarid climate in which the subbasin evolved. Large planar crossbeds associated with trough crossbedding suggest that sandy braided streams (Miall, 1978; Walker, 1979) were established upon the delta platform.

The destructive phase of the cycles occurred after delta abandonment when lake level was maintained or rose. At such times, the delta sands were reworked by wind-generated wave activity into beaches and rippled sand flats in interdistributary bays or over the delta top.

Calcareous mud, gray shales and minor carbonates were deposited offshore along shallow, interdistributary bays and agitated shorelines. The dolomitization of the carbonate deposits is suggestive of high Mg-Ca ratios (Müller et al., 1972) and high evaporation rates (von der Borch and Lock, 1979) in the shallow lake waters. A limited, soft-bodied fauna frequented the zone between the rippled sandflats and the offshore shale.

Shallow lacustrine to shoreline conditions were maintained in the southwest of the subbasin into the late stages of development of the Friars Cove Formation. The generally gray rocks formed in these environments underlie basal strata of the Codroy Group as far north as the "round valley" and the North Branch of the Grand Codroy River. Here, however, a transition occurs northwards into sandy, red alluvium of the Spout Falls Formation. It appears that south of this transition braided streams that carried coarse pebbly to sandy detritus from the southeast margin into the axial zone of the subbasin caused the lake to shrink appreciably in size at times.

Spout Falls Formation

Definition and distribution

A complex of geographically separated fluviatile rock sequences are here grouped together in the Spout Falls Formation. They include:

(1) Red and gray sandstones with minor siltstones and conglomerates that underlie the northern half of Anguille Mountains, Bald Mountain and continue northeast adjacent to the Long Range Fault almost to Barachois Brook. They are equivalent to the upper red sequence of the Seacliffs Formation of Baird and Cote (1964).

(2) Gray and minor red conglomerates and sandstones called the Fischells conglomerate member (Baird, 1951). This forms the core of the Flat Bay anticline and occurs faulted against the Steel Mountain anorthosite massif along Sheep, Coal and Flat Bay Brooks. Belt (1969) called it the Fischells Brook Formation. A thin (1-2 m) conglomerate that lies beneath basal Codroy Group limestone (Windsor subzone A, von Bitter and Plint-Geberl, 1982) on the Port au Port Peninsula and at Romaines Brook at the northern margin of the subbasin is included in the Fischells conglomerate member.

(3) Basal strata of a thick sequence of fault-bounded, red arkosic rocks informally defined by Fong (1976) as the Brow Pond lentil may also be time equivalent to strata of the Spout Falls Formation. The basal strata are tilted, gently folded and overlain unconformably by arkosic rocks comprising the rest of the lentil.

The formation is named after "The Spout Falls", a waterfall descending the cliffs at the mouth of Spout Gulch. No type section was measured but one incomplete section was logged in Friars Cove (see Figure 8). The formation is well exposed in most streams northwest of the Snakes Bight fault, but elsewhere in the Anguille Mountains and Bald Mountain, it is poorly exposed.

The basal contact of the Spout Falls Formation in the Anguille Mountains is gradational and is defined relative to the top of the Friars Cove Formation. Southward lensing out of the former formation into the latter formation may indicate a diachronous basal contact. In the Flat Bay anticline, the Fischells conglomerate member probably lies unconformably upon Precambrian gneisses in the Flat Bay anticline (Fong, 1976a; Fong and Douglas, 1975). The presence of this subsurface basement is inferred from a positive magnetic anomaly (Geological Survey of Canada, 1968) in the north of the anticline.

The basal arkoses of the Brow Pond lentil also lie unconformably against the Mt. Howley anorthosite. The steep, straight, northern contact with the anorthosite suggests an exhumed Carboniferous fault scarp. An unconformity may also occur at the eastern edge of the lentil where a positive magnetic anomaly occurs near the junction of the Long Range fault and the steep, western margin of the Steel Mountain anorthosite. Gradually decreasing geomagnetic response westward over the lentil suggests basement gradually becomes deeper beneath the cover.

The top of the Spout Falls Formation is placed throughout the subbasin at the base of the Ship Cove Formation.

Thickness

The Spout Falls Formation forms a northeastward thickening prism of sediment. South of the "round valley", Codroy lowlands, Spout Falls lithologies are seen as thin intercalations within the strata of the Friars Cove Formation. They are not separable on the scale of the accompanying map. The formation is 780 m thick northwest of the Snakes Bight Fault but it is calculated to thicken to at least 2250 m just west of Codroy Pond at the north end of the Anguille Mountains. This marked thickening is attributed to active, fault-controlled, syndepositional subsidence. This notion is further supported by the thickening of Friars Cove Formation across the same Snakes Bight fault.

The Fischells conglomerate member is estimated to be 100 to 150 m thick (Fong, 1976; Fong, personal communication, 1976) in the Flat Bay anticline and at least 200 m thick along Coal Brook (Baird, 1949).

General lithology

The Spout Falls Formation in the Anguille Mountains and Bald Mountain consists of well indurated to friable, red, reddish-gray, gray and green calcareous, arkosic and micaceous sandstones. Conglomerates, intraformational conglomerates and minor siltstones and shales also occur.

The succession is dominated by fluviatile sandstones exhibiting abundant scouring, and a well bedded, sheet-like geometry (Plate 28). Mudchips, intraformational conglomerates, abundant parallel stratification and lesser quantities of crossbedding are present. Siltstones are uncommon and conglomerates are sporadically distributed. The 250 m thick incomplete section at Friars Cove delineates no fining- or coarsening-upward grain size trends. However, Cote (1964) measured a generalized, incomplete section of 500 m on Lewis Gulch which shows the upper 250 m to be slightly more granular and pebbly than the lower part of the section.

Plate 28: Cliffs on the north side of Hynes Cove showing the characteristic sheet-like geometry of the red and grayish red sandstones of the Spout Falls Formation along the south shore of St. George's Bay. Some of the beds clearly lens out and a number of scours are present beneath sandstone beds. Beds are inverted and young to the left.

As the Spout Falls Formation is traced northeastward, lenses and thin beds of conglomerate become more abundant, particularly adjacent to the Long Range fault northeast of Bald Mountain. Rounded to subangular pebbles consist overall of red granite which may be porphyritic, gray granite gneiss, porphyritic and aphanitic brown and green silicic volcanics, white quartz, white quartzite and limestone. Quartzite and limestone clasts are noticably absent, however, in exposures on Bald Mountain. Pebbles only 8 mm in maximum dimension occur in the Friars Cove section but they increase in size to 12 cm in diameter farther northeast at Lewis Gulch and around the northern closure of the Anguille anticline.

The Fischells conglomerate member is composed of gray and red, well indurated, polymictic conglomerate and lenses of sandstone. An approximately 20 m thick unit of flaggy, gray sandstones occurs in the middle of the member on the east side of the anticline on Fischells Brook (D. Rogers, personal communication, 1981). The member consists of gray strata in the north of the Flat Bay anticline but gray beds are intercalated with red sandstones in the south near Robinsons River. Gray conglomerates extend as far south as the Highlands River where they are interbedded within gray and red sandstones near the northern closure of the Anguille anticline (Fong, personal communication, 1976). Red and gray beds occur in the member near the Steel Mountain anorthosite (Baird, 1949).

The conglomerates of the Fischells conglomerate member consist of rounded and subrounded pebbles and cobbles near Steel Mountain, and pebbles in the Flat Bay anticline. The clasts in the latter locality were mostly derived from the erosion of Cambro-Ordovician carbonate rocks supplemented by white quartz, red jasper, granite, silicic volcanic and metamorphic clasts shed from the central Newfoundland uplands. Near Steel Mountain, they consist of vein quartz, white, buff and reddish quartzites, several granitic rock types, diabase, some basic plutonic lithoclasts, gray, commonly cherty limestone and red shale (Baird, 1949).

Six lithofacies have been delineated in the Spout Falls Formation. Some are observable in the section at Friars Cove. They are (A) thick bedded sandstone lithofacies, (B) stratified sandstone lithofacies, (C) fining-upward sandstone-siltstone lithofacies, (D) sandstones with large scale crossbeds (E) siltstone – very fine sandstone lithofacies and (F) conglomerate lithofacies.

(A) THICK BEDDED SANDSTONE LITHOFACIES

Description of lithofacies A: Lithofacies A consists of red, gray and green sandstones, pebbly sandstones, minor conglomerate, intraformational conglomerate, thin shaly siltstones and shales in sequences up to 10 m thick. It comprises some 41% of the incomplete section measured on Friars Cove and is characterized by beds, 20-60 cm and locally 2 m thick, of medium to very coarse grained sandstone. The beds have a sheet-like geometry, vary in thickness along the bed and may be separated by thin siltstones or shale partings (Sections 1, 2, 3, Figure 14).

Sandstone beds within this lithofacies begin with planar, broadly curved or irregular scours which are overlain by one or more of the following: (1) small pebble conglomerates or intraformational conglomerates with clasts locally concentrated in the scour depression; (2) well to poorly defined, horizontal to slightly inclined stratification with some solitary crossbeds; (3) structureless beds of sandstone or pebbly sandstone (Section 1, 2, Figure 14); (4) planar cross-stratification which may also overlie a basal conglomerate; and (5) trough crossbeds overlain by some laminated and cross-laminated rocks. Grain size and sedimentary structure size decrease upwards in some sequences where planar crossbeds are overlain by trough-crossbedded and/or laminated horizons. Trough-crossbeds, which locally contain convoluted foresets, are 10 to 25 cm thick, and 10 to 200 cm in length. Isolated cross-sets in laminated beds have broad shallow scours, 1.5 to 2 m wide and 10 to 20 cm deep. They are

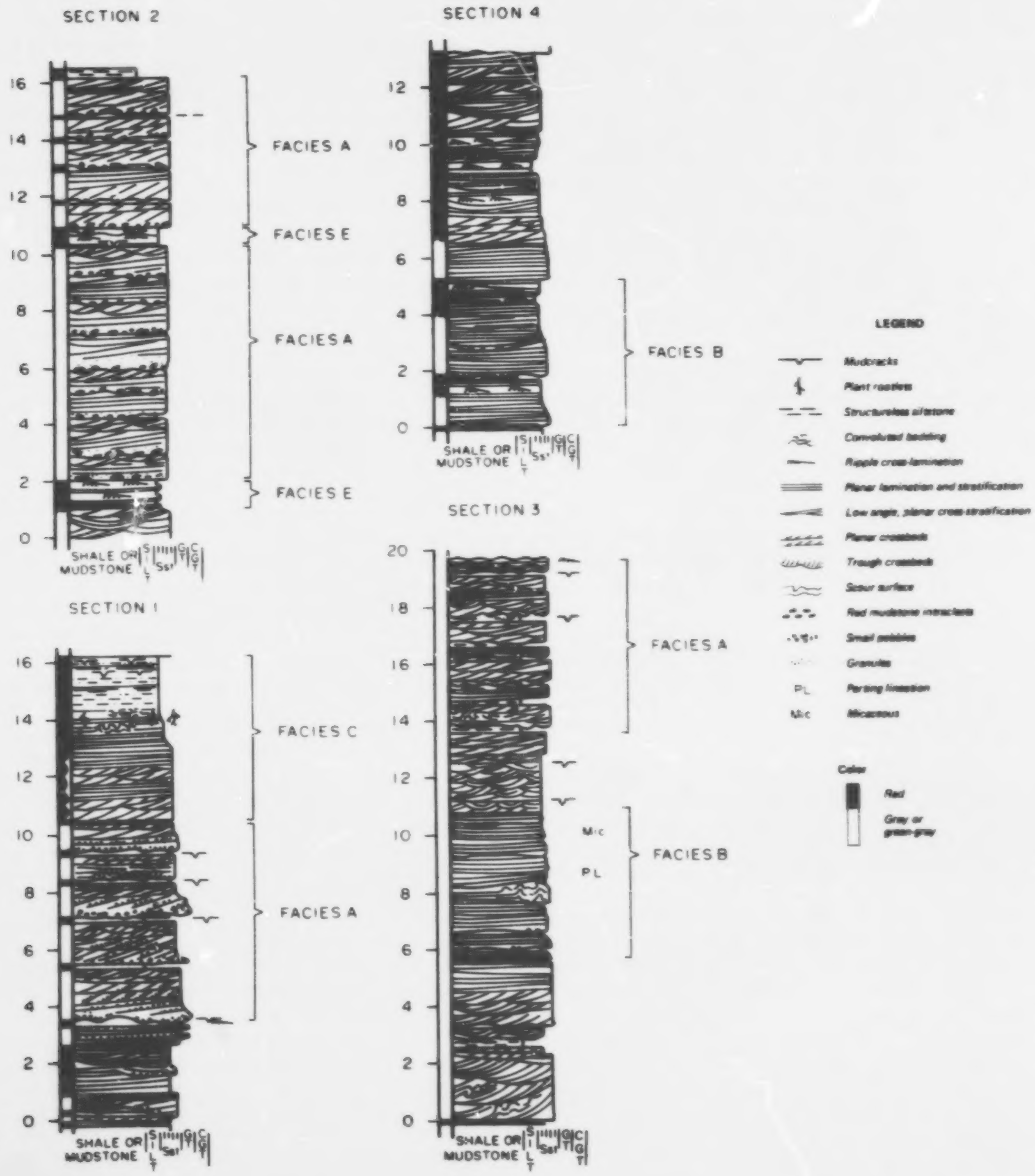

SECTION 2
16
14
12
10
8
6
4
2
0
FACIES A
FACIES E
FACIES A
FACIES E
SHALE OR MUDSTONE
SILT
Ss'
GT
CGT
SECTION 4
12
10
8
6
4
2
0
FACIES B
SECTION 1
16
14
12
10
8
6
4
2
0
FACIES C
FACIES A
SECTION 3
20
18
16
14
12
10
8
6
4
2
0
FACIES A
Mic
PL
FACIES B
LEGEND
Mudcracks
Plant rootlets
Structureless siltstone
Convoluted bedding
Ripple cross-lamination
Planar lamination and stratification
Low angle, planar cross-stratification
Planar crossbeds
Trough crossbeds
Scour surface
Red mudstone intraclasts
Small pebbles
Granules
PL
Parting lineation
Mic
Micaceous
Color
Red
Gray or green-gray

Figure 14: Detailed sedimentological sections in the Spout Falls Formation at Friars Cove.

filled concordantly by stratification similar to the Zeta or Theta cross-stratification of Allen (1963). Ripplemarks occur on the tops of some beds.

Shaly siltstone and shale beds up to 15 cm thick are interbedded with the sandstones. In many cases, however, shale partings and drapes separate the sandstone beds. The shales are commonly mudcracked.

Interpretation of lithofacies A: The characteristics of lithofacies A suggest deposition in shallow, sandy braided streams. Separation of sandstones by mudcracked layers of shale and siltstone may indicate that each sandstone bed represents a distinct depositional event. This further implies that the braided fluvial system either was ephemeral or was characterized by rapid lateral shifting of channels.

The erosional bases, abundant mudclasts and sheet-like geometry of the sandstones support an interpretation based on frequent lateral shifting of channels and erosion of previously deposited units. Deposition within channels was variable. Horizontal and low angle planar, crude stratification was perhaps formed in longitudinal bars (Smith, 1970). Such stratification likely represents plane beds produced by currents with velocities characteristic of the upper flow regime (Simons et al., 1965; Southard, 1975). Planar cross-stratification formed within transverse or linguoid bars (Williams, 1966, 1971; Collinson, 1970a; Smith, 1972). Trough-crossbeds formed within megaripples (Harms, 1975; Cant and Walker, 1978; Walker, 1979a) that migrated along channels or over channel bars as described for ephemeral and large perennial, braided river channels (Williams, 1967, 1971; Collinson, 1970a; Karcz, 1972; Cant and Walker, 1978). Fining-upward units illustrating the change from planar stratification to crossbedding and cross-lamination or lamination without parting lineations (lower plane bed, Harms, 1975) indicates that deposition was caused, in some instances, by gradually waning currents.

(B) STRATIFIED SANDSTONE LITHOFACIES

Description of lithofacies B: Gray, arkosic and micaceous sandstones, 5 m thick, (Section 3, Figure 14) and units of gray sandstone grading to red sandstone, 2-4 m thick (Section 4, Figure 14) comprise this lithofacies. The fine grained sandstones are mostly ungraded but some units fine upward. Lithofacies B composes 51% of the section measured in Friars Cove.

The facies generally displays a characteristic, 1-4 cm spaced planar stratification cross-cut at 30 to 60 cm intervals by broad, planar scours. Parting lineations are most common in the lower parts of the sequence but not in the upper, finer grained, red sandstones. Ripple cross-lamination and convolute bedding also occur and some bedding planes are blackened by fine plant trash. Pea-size mudclasts occur above some of the scours.

A slightly different sequence is illustrated in Plate 29. Here a basal scour is overlain by more than 2 m of stratified sandstone without internal scours. The deposit is capped abruptly by red siltstone.

Interpretation of lithofacies B: Lithofacies B is characterized by thick sequences of planar stratified and laminated sandstones rich in parting lineations. These stream deposits formed in the upper flow regime (Allen, 1964b; Simons et al., 1965; Southard, 1975); the stratification may have formed over a wide range of flow velocities because of the generally uniform, fine grain size (Simons et al., 1965).

The regular development of scours and the general lack of lower flow regime structures suggests that the deposits were mostly built up by a

Plate 29: Planar stratified, gray sandstones of lithofacies B, Spout Falls Formation, interbedded with thin red siltstone (lithofacies E). Trans Canada Highway, north of Highlands River. Scale one metre.

repetitive fluvial process. It involved high flow energy and rapid current deceleration, so that erosion was followed mostly by the production of sedimentary structures of the upper flow regime. Such properties are characteristic of flashflood-generated, ephemeral streams in areas of semiarid climate (McKee et al., 1967; Williams, 1971; Picard and High, 1973; Frostick and Reid, 1977; Tunbridge, 1981a and b). They are untypical of perennial meandering or sandy braided systems which controlled the deposition of the intercalated rocks of lithofacies A (Allen, 1964a, 1965a, 1965b; Smith, 1970; Cant and Walker, 1976; Miall, 1977; Walker, 1979a).

Thick lithofacies B sandstones that lack internal scouring, overlie a sharp, erosive base and are capped abruptly by red siltstone, may be channel fills produced by stream flow in a single major flood. The channels were rapidly abandoned and hence channel fill was abruptly overlain by a siltstone layer deposited by vertical accretion.

(C) FINING-UPWARD, SANDSTONE-SILTSTONE LITHOFACIES

Description of lithofacies C: Lithofacies C is formed of gray to red, coarse or medium, often pebbly, sandstones grading up into very fine red sandstone and siltstones. The sequences, which are 3.5 to rarely 15 m thick, are not very common. Irregular, 1 m deep, channel scours are locally associated with intraformational mudchip or pebble conglomerate and some plant debris. Sedimentary structures in overlying coarser sandstones include trough-crossbedding and planar lamination (Section 1, Figure 14); minor ripple cross-lamination may also occur. Crossbeds vary in thickness from 10 to 25 cm with sets up to 200 cm wide.

Very fine, often micaceous red sandstones and siltstones form the top beds of facies C sequences. Wavy lamination, thin bedding, ripple-drift, plant rootlets and thin lenticular layers of red siltstone occur in the sandstones. Siltstone beds are 1-3 m thick. They are bright red and structureless except for faint lamination, waxy shale partings and thin green layers. Plant rootlets, mudcracks and small calcareous nodules (caliche) occur in some of the siltstones.

Interpretation of lithofacies C: The trough-crossbedded and planar laminated, fining-upward sandstones of lithofacies C that overlie basal scours with an intraformational or pebble lag, are here interpreted as channel-fill deposits. Irregular basal scour and abundant mudclasts at the base of infills are distinguishing features of channel floor and lag deposits commonly found at the base of fluvial sequences (Allen, 1965a,b; Walker, 1979a). Such deposits are suggestive of active bank erosion and lateral migration of channels. Trough-crossbedding overlain in some units by planar lamination may imply the presence of in-channel megaripples (dunes) and upper flow regime plane beds (Harms, 1975). These structures, as well as ripple cross-lamination and an upward grain size reduction, generally indicate a waning current flow. Thick siltstones gradationally overlying the channel sandstones suggest channel abandonment with infill by fine, vertical-accretion deposits.

The general character of the sandstone bodies bears some resemblence to that ascribed to sandstone deposits of meandering streams (Allen, 1965a; Walker, 1979). Nonetheless, the association of the facies with strata deposited mostly by shallow braided and ephemeral streams suggests that lithofacies C sandstones were deposited in low sinuosity stream channels.

(D) SANDSTONES WITH LARGE SCALE CROSSBEDS

Description of lithofacies D: Sandstones composed of very large scale, high angle, planar crossbeds at least 5 m in thickness were noted only once in the Spout Falls Formation and that was in a cliff on Lewis Gulch (Plate 30).

Plate 30: Very large scale, planar crossbeds overlain by cosets of large scale, trough-crossbeds (lithofacies D), in steeply dipping beds of Spout Falls Formation; beds young to left. The huge crossbeds lie against a broad, deep channel scour. The top of the cross-sets was eroded by a planar scour which was in turn overlain by the large crossbeds. Location Lewis Gulch.

The crossbeds, with an apparent east-northeast dip, lie against the side of a large, elliptical scour which cuts deeply into the underlying strata. The large crossbeds are themselves truncated by a planar scour which is overlain by planar and trough-crossbeds.

Interpretation of lithofacies D: Large crossbeds of the scale of those seen in Lewis Gulch are known to form in association with deep channels as: (1)

alternate bars attached to channel margins (McCabe, 1977); (2) large sand waves within river channels similar to those described by Conaghan and Jones (1975) and Coleman (1969); or (3) a s delta-like deposits infilling abandoned river channels or forming at the confluence of two deep channels (McCabe, 1977).

An alternate-bar model is favoured here because the large crossbeds are attached to one margin of a large channel. Smaller scale crossbeds overlying the large sets are probably similar to the medium scale crossbeds formed by migrating megaripples. Such deposits are reported to overlie the alternate bars of deep channels in the Upper Carboniferous of Yorkshire (McCabe, 1977).

(E) SILTSTONE - VERY FINE SANDSTONE LITHOFACIES

Description of lithofacies E: Red and gray siltstone and very fine sandstone form uncommon (less than 2% of measured section, Friars Cove) but distinct units, 10-80 cm thick in strata dominantly composed of lithofacies A and B (section 2, Figure 14). Beds within lithofacies E units are 5 to 20 cm thick. Planar and wavy lamination, ripple drift, mudcracks and plant rootlets are common structures.

Interpretation of lithofacies E: Grain size and sedimentary structures suggest that the sandstones and siltstones were deposited by slow, shallow currents in standing water bodies. They resemble facies Fl of Miall (1977) and facies a and b of the Donjek River (Williams and Rust, 1969) which were deposited in shallow pools, abandoned channels, or marginal areas in a braided river system. Mudcracked horizons suggest the pools and channels were frequently dessicated.

(F) CONGLOMERATE LITHOFACIES

Description of lithofacies F: Lithofacies F is found in the Fischells conglomerate member. It consists of conglomerate beds, several metres thick, and some sandstone. The conglomerates have erosional bases and are mostly internally massive. Crude horizontal stratification is visible where long axes of pebbles lie parallel to bedding; some pebbly crossbeds also occur. Sandstones in beds and lenses mostly up to 2 m thick are generally planar stratified or crossbedded; they locally infill irregular depressions in the tops of conglomerate beds.

Interpretation of lithofacies F: The conglomerates with lenticular sandstones are probably deposits of gravelly braided streams (Rust, 1972; Miall, 1977). Erosive bases overlain by thick conglomerate units with lenticular sandstones imply shifting and fluctuating flow conditions. The massive to stratified conglomerates were deposited in longitudinal bars. Crossbedded deposits were likely laid down in transverse bars (McDonald and Banerjee, 1971; Smith, 1974).

Paleocurrents in the Spout Falls Formation

Only a few current directions were collected, most of which are parting lineations and other small scale structures. They give a generally southerly direction of transport for the sandy facies in the Anguille Mountains. Southeasterly paleoflow occurs at Friars Cove but in the central area of the Anguille Mountains, there is a southerly to southwesterly paleoflow.

Age and correlative deposits of the Spout Falls Formation

Similar redbed sequences are found near the top of the Horton Group throughout much of the Maritimes Basin where they underlie the basal limestones of the Windsor Group. The latter are equivalent to the Ship Cove limestone of the Codroy Group. The Spout Falls Formation is correlated with the Cheverie Formation (Bell, 1960) of Nova Scotia. Cote (1964) correlated it with the Ainslie Member of the Ainslie - Strathlorne Formation (Kelley, 1967a) of Cape Breton. Redbeds of the Weldon and Hillsborough Formations in New Brunswick (Gussow, 1953; Greiner, 1962) (see Table 2) are thought to straddle the time period of the upper Horton Group and lower Windsor Group.

Belt (1969; personal communication, 1981) has suggested that the Fischells conglomerate member is Windsorian in age. However, this is based upon spores identified in shales at the base of the overlying Ship Cove Formation which are clearly not part of the conglomerate sequence.

Depositional environment of the Spout Falls Formation

The dominantly red strata of the Spout Falls Formation were deposited in a sandy and gravelly fluviatile environment that prograded southward over the lacustrine-deltaic sediments of the Friars Cove Formation. By the end of Anguille deposition, the redbeds filled the subbasin as far south as the Round Valley and, for brief intervals, blanketed the subbasin in the southwest (e.g. lithofacies E of the Friars Cove Formation).

The Spout Falls Formation is dominated by a thick succession of red fluvial sandstones that accumulated in the axial region of the subbasin. It is characterised by deposits of shallow, sandy, braided and ephemeral streams (lithofacies A & B). The unique sheet-like geometry of the succession compares closely to the braided-sheet, fluvial style of Cotter (1978). He interprets such rocks to be indicative of the vegetation-free environments of semiarid areas. The importance of planar stratification in the sheet sandstones suggest that ephemeral sheetflood and channelwash dominated the fluvial environment. Flashfloods, which are very typical of semiarid climatic areas (Cooke and Warren, 1973; Frostick and Reid, 1977), controlled these deposits. Sediment was then reworked downslope from basin margins towards the basin axis to form a sandy flood plain. Tectonic instability and rapid subsidence in the subbasin maintained steep, stream gradients. These gradients allowed strong currents to sweep fines through the flood plain and contributed to the general lack of overbank siltstones in the formation. Nevertheless, some fining-upward channel sandstones, capped by overbank red siltstones (lithofacies C), suggest that low sinuosity streams did cross the flood plain at times. Sandstones with large scale crossbedding (lithofacies D) also support the presence of some large river channels within the subbasin. The deposits interpreted as alternate bars are similar to strata displaying epsilon cross-stratification (Allen, 1963). Leeder (1973) used this type of stratification to define channel depth. It appears that these crossbeds in the Spout Falls sandstones formed in a channel with a depth greater than 5 m and a width of possibly hundreds of metres (cf. McCabe, 1977). A channel of this magnitude indicates the presence of a large perennial river. It probably supplied the sandy, fluvially dominated deltas of the Friars Cove Formation to the south. The paucity of overbank fines in the succession most likely means that the river was entrenched in its sandy flood plain and was perhaps internally braided. (cf. Coleman, 1969; Collinson, 1970a; Cant and Walker, 1978).

Alluvial fans composed of sands and gravels were likely deposited along the edges of the subbasin although little data is available from the Spout Falls Formation in these areas. Increasing pebble content together with the composition of sands and pebbles near the Long Range fault support the idea of a build-up of alluvial fans along the primordial structure. Basal arkoses of the Brow Pond lentil may have been deposited as a coarse, sandy, alluvial fan at approximately the same time in the northeast corner of the subbasin. South to southeastward paleocurrents as well as pebbles of Lower Paleozoic platformal rocks from northwest of the Snakes Bight fault seem to indicate that similar sandy and gravelly fans developed along the southeastern margin of the Humber Arm allochthon highlands.

Active subsidence in the subbasin during Spout Falls deposition was centred at the north end of the Anguille anticline, southeast of the Snakes Bight fault. The absence of a lacustrine facies in this area suggests that substantial sediment accumulation was maintained by the sandy, braided, fluvial system. It also implies steady resedimentation of alluvium from the marginal alluvial fans to the axis of the subbasin. High sedimentation rates prevented the formation of meandering rivers.

Caliche is notable by its general absence in a succession thought to have been deposited in a semiarid climate. This feature, however, probably reflects the high sedimentation rate (Leeder, 1975). The commonly observed calcareous cement of the Spout Falls sandstones is, however, known to form rapidly in semiarid climatic regions, particulary in sands that are deposited near limestone uplands (Glennie, 1970; see also Frostick and Reid, 1977, page 2). A semiarid climate is evidenced by (a) lack of vegetation, (b) sheeted, ephemeral stream deposits dominated by planar stratification (Frostick and Reid, 1977; Cotter, 1978; Tunbridge, 1981a), (c) fresh detrital grains (Folk, 1968) and (d) ferruginous impregnation and coating of detrital grains (Walker, T.R., 1963, 1967a and b; Glennie, 1970; Cooke and Warren, 1973).

The conglomerates of the Fischells conglomerate member are interpreted as gravelly, alluvial fans. They were deposited in close proximity to their source, the Humber Arm allochthon highlands. The gravel fan was formed late in the depositional history of the Spout Falls Formation, probably apart from the hypothetical, alluvial fan deposits that were reworked to form the thick, sandy, axial, basin-fill succession. The Fischells conglomerate member may not be laterally persistent. It is most likely a local deposit restricted to the area of the Flat Bay anticline; that it extended along the entire northwest margin of the subbasin is improbable.

Precambrian crystalline rocks that appear to underlie much of St. George's Bay area (McKillop, 1959; Spector, 1969; Golden Eagle Developments Ltd., 1975) are overlain by the Codroy Group. Here any sub-Codroy strata are anticipated to be similar to the conglomeratic facies of the Fischells conglomerate member. Such conglomerates, however, appear to thin northward from Flat Bay (150 m) to Romaines Brook (2 m) at the northern edge of the basin, and may be absent under much of the bay.

Evidence that the Fischells conglomerates formed contemporaneously with the upper part of the Spout Falls Formation is not conclusive. This concept is supported, however, by gray pebble beds intertonguing with Spout Falls sandstones at the northern closure of the Anguille anticline, and red sandstones in the conglomerates at the southern end of the Flat Bay anticline (Fong, personal communication, 1976). The thick wedge of flaggy sandstones intercalated with the conglomerates on the east limb of the anticline also suggest a rapid southeastward transition from the conglomerates into sandstones. This might imply that the conglomerate member formed a narrow, gravel bajada along the northwest, fault-bounded margin of the subbasin for some time.

Petrography of the Siliciclastics of the Anguille Group

The sandstones of the Anguille Group include lithic arkoses, arkoses, subarkoses and sublitharenites (Folk, 1968). Examination of more than thirty thin sections revealed that detrital components are consistent from one formation to another, although variations occur from place to place within the same formation. The sandstones contain abundant perthite and microcline grains in association with fragments from high level granitic intrusions that have graphic and granophyric textures. Grains of silicic volcanics and low grade metamorphic rocks are also common.

In general, the sandstones are moderately well sorted to poorly sorted (Beard and Weyl, 1973). They are well sorted in ripple bedded, calcareous sandstones of the Friars Cove Formation and some of the red sandstones of the Spout Falls Formation. Grains in general are angular to subrounded so that feldspars retain prismatic shapes with only rounded corners; heavy minerals are prismatic or irregular in shape. Grains show better rounding in well sorted, rippled sandstones of the Friars Cove Formation.

Matrix and cement variably fill intergranular space in the sandstones. Grain contacts, suturing and annealing are common and quartz overgrowths occur. Fine, felted chlorite comprises the matrix of the Kennels Brook sandstones and some sandstones of the Snakes Bight and Friars Cove Formations. It is most common, however, to find the Anguille Group sandstones cemented by carbonate and locally silica. Etching of quartz grains by carbonate is variable and preferential replacement of feldspars by carbonate cement occurs along cleavage planes, in perthitic phases or around grain edges. Pyrite and limonite are common in the gray sandstones; hematite and limonite coat sand grains in redbeds of the Spout Falls Formation.

Single and composite quartz grains are present in the Anguille Group sandstones. Single grains include both unstrained and variably strained quartz. The latter shows undulose extinction, deformation lamellae and slight recrystallization. Vacuoles, vacuole trails, rutile needles, small muscovite plates, some apatite and less tourmaline occur within quartz grains. Some quartz grains in the Friars Cove Formation in the southwestern outcrops of the group are clear. They lack vacuoles and some grains have embayed boundaries. These characteristics may indicate that such clear grains were once quartz phenocrysts in subvolcanic granites or silicic volcanics. 'Common' composite quartz (Folk, 1968) of vein and plutonic origin is otherwise ubiquitous. Composite grains of metamorphic origin include very anisotropic grains with extreme crystal elongation and smooth crystal contacts suggesting mylonitic quartz, stretched quartz with sutured crystal contacts, schistose quartz with small oriented muscovite flakes and granoblastic quartz.

Microcline and perthite are abundant in the sandstones with variable quantities of plagioclase and orthoclase. Plagioclase, which appears to be mostly oligoclase, is as abundant as K-feldspar in parts of the Kennels Brook and Snakes Bight Formations. It was rarely encountered in sectioned sandstones from the Spout Falls Formation. Microcline and perthite dominate in the Friars Cove Formation. Feldspars are fresh to altered, with varying degrees of sericitization and vacuolization common. Vacuolization affected alkali feldspars, particularly in sandstones of the Friars Cove Formation on Codroy Island. In situ degradation of feldspars was not noted.

Large plates and flakes of muscovite, biotite and chlorite occur in the sandstones. Muscovite and chlorite are most common but these micas rarely form more than a few percent of the sandstones and, in some Friars Cove rocks, they are absent. Biotite is the least common mica. Green biotite was, however, noted in Friars Cove sandstones from Codroy Island, in the Spout Falls Formation in the north of the Anguille Mountains and in sandstones of the Fischells conglomerate member along Fischells Brook. Iron oxides generally impregnate or speckle muscovite and biotite, and radioactive haloes were noted in some khaki colored biotites.

Plutonic rock fragments consist of quartz-plagioclase or quartz-alkali feldspar ± micas. Although they are common in the coarser sandstones, they are absent in thin sections of Kennels Brook sandstones. Mafic and silicic volcanic rock fragments may be important or absent. Mafic clasts usually consist of plagioclase microlites set in a chloritized groundmass speckled by iron oxides; some contain larger lath-shaped plagioclase crystals. Felsic volcanic grains display spherulitic, felted, feathery and indistinct devitrification textures. Porphyritic cherts and quartz-feldspar porphyrys also occur. The latter are particularly prominent in pebbly arkoses of the Friars Cove Formation, Codroy Island, where they are associated with fresh red microclines.

Apart from phyllites, chlorite schists and quartz-sericite or muscovite schists, metamorphic grains are rare. Some metachert resembling deformed silicic volcanics of the Windsor Point Group (Chorlton, personal communication, 1981) and metaquartzite grains occur. Sedimentary grains include uni- or poly-crystalline calcite, siltstone and very fine sandstone and some chert.

Zircon and tourmaline in large and small grains dominate the heavy mineral suite. Zoned, twinned and prismatic, green, yellow and brown tourmalines occur. Garnet, epidote, rare brown hornblende, rare sphene and possible red rutile were also noted. Magnetite, hematite and leucoxene are scattered in the sandstones or are locally concentrated in laminae in rippled sandstones of the Friars Cove Formation.

Age and Correlative Deposits of the Anguille Group

The upper part of the Anguille Group is of Early Mississippian age (Baird and Cote, 1964). The group can be correlated with the Horton Group of Nova Scotia (Hayes and Johnson, 1938; Bell, 1948; Baird and Cote, 1964) which is Famennian to Tournaisian in age (Playford, 1963; Hacquebard, 1972). The lithostratigraphy of the Hortonian rocks of Maritime Canada is summarized in Table 2. In Newfoundland, sedimentary rocks of Tournaisian age are also assigned to the Anguille Group in the Deer Lake Basin (Hyde, 1978, 1979a,b; Hyde and Ware, 1980, 1981).

Miospores and plant fossils from the Anguille Group are rare and badly preserved (Cote, 1964; Barss, personal communication, 1979). Only one sample out of thirty-five processed for spores (Cote, 1964) yielded a spore assemblage. No spores were found in several samples collected by the author (Barss, personal communications, 1979). Cote's one sample collected from a location on the north shore of Snakes Bight in the Cape John Formation (Cote, 1964) yielded an assemblage apparently slightly older than those of the Craignish Formation of Cape Breton (see Table 2) and the Horton type sections of Bell (1960) in Nova Scotia. The location of this sample is uncertain and in light of a structural reinterpretation of this particular area, the sample may belong to the uppermost Spout Falls Formation rather than the basal Kennels Brook Formation, suggesting that much of the Anguille Group be Devonian. Bell (1948, page 5) identified several plant fragments from the Anguille Group and concluded they suggested an age equivalent to the upper part of the Horton Group.

Although a Tournaisian age is generally accepted for much of the Horton Group, opinions vary as to its time duration. Hacquebard (1972) suggested that the group extended throughout the Tournaisian. Geldsetzer (1978), however, speculated that Horton sedimentation was confined to the lower part of the Tournaisian. For the Maritimes Basin, this implies a depositional hiatus of several million years after the accumulation of the

Horton Group. The possible hiatus would have lasted till at least the middle Viséan (Mamet, 1970) when the sediments of the overlying Codroy and Windsor Groups were deposited.

Summary and Geological History of the Anguille Group

The geological data presented above shows that the Anguille Group consists of a sequence of nonmarine fluviatile and lacustrine strata laid down in a generally narrow, tectonically active basin. Sedimentation within the Bay St. George subbasin at this time reflects the infill of a fairly deep, elongate lake, following dominantly fluvial sedimentation in the late Devonian, as summarized in Table 3.

The Kennels Brook Formation consists of fluvial redbeds and some lacustrine strata that were probably deposited during the late Devonian. This formation, which is more than 3200 m thick beneath the Anguille Mountains, is unknown elsewhere in western Newfoundland. It probably represents a pre-Horton/Anguille phase of sedimentation.

Redbeds of the Kennels Brook Formation may have formed part of an extensive molasse blanket. This post-Acadian molasse would have extended westward out into the Gulf of St. Lawrence area (Haworth and Sanford, 1976) from source mountains southeast of the Long Range fault. Erosion of much of this blanket may have occurred, prior to Codroy Group deposition, when the Humber Arm allochthon highlands formed northwest of the subbasin. Alternatively, the redbeds may have been locally developed as a thick basin-fill sequence confined to a fault graben.

If thick, nonmarine Devonian molasse did flood a successor basin west of the Acadian fold belt, it is possible that sedimentation began as early as the Early Devonian when the Clam Bank Formation (Rodgers, 1965; O'Brien, 1975) was deposited. This formation, which is tilted steeply westward in fault contact with Cambro-Ordovician platformal rocks, occurs at the western edge of the Port au Port Peninsula. It contains no carbonate detritus, yet has westerly directed paleocurrents (H. Williams, personal communication, 1978). The Lower Devonian redbeds might have buried large parts of the Cambro-Ordovician platform.

The substantial thickness of the Kennels Brook Formation is in keeping with the notion that molasse sedimentation could have been maintained in western Newfoundland throughout the Devonian. Tectonic activity leading to uplift, sedimentation, volcanism and deformation also occurred during the Devonian particularly along the Cape Ray fault system (Brown, 1977; Chorlton and Dingwell, 1981; Kean and Jayasinghe, 1981). Compressive stresses were probably released along major faults so that variably sized successor basins were widely distributed in depressions and along faults in and peripheral to the Acadian fold belt.

A major cycle of sedimentation that includes the remaining three formations of the Anguille Group followed the Devonian molasse sequence. It records the history of formation and infill of a lacustrine basin.

An inland drainage basin was formed in which lacustrine conditions were rapidly established as the basin was supplied by rivers draining from central Newfoundland and uplands to the north. The lake was relatively steep-sided and possibly up to 100 m deep at its maximum development. It was initially filled by a deep water lacustrine sequence, the Snakes Bight Formation, that was deposited over a period of at least 300,000 years. Turbidites were deposited in the lake, possibly on sublacustrine fans in front of steep-fronted deltas. Quiet water, basinal muds typical of a stratified, meromictic lake were laid down extensively in the lake. This lake shallowed at an accelerating rate as sandy deltas encroached along the basin

TECTONIC EVENT HUMBER ARM ALLOCHTHON HIGHLANDS	TECTONIC EVENT IN SUBBASIN	BAY ST. GEORGE SUBBASIN				TECTONIC EVENT S.E. OF LONG RANGE FAULT	STAGE
			STRATIGRAPHY		SEDIMENTATION		
	Basin Deformed by Wrench, Then by Vertical Block Faulting					Vertical Faulting or Strike-Slip Faulting	Stephanian? or Post-Pennsylvanian
	Subsidence		Barachois Group includes Searston Formation		Fluvial and Coal Beds Fluvial	Uplift	Westphalian A Namurian A
Upland Terrain No Longer Major Detrital Source	Subsidence Localized Near Long Range Fault?	CODROY GROUP	BPL? Overfall Brook Member ? Woody Cape Formation Mollichignick Member	ROBINSONS RIVER FM	AF Alluvial Fan Deltaic Fluvial + Minor Marine AF	Uplift Uplift	Visean
	Subsidence in Fault - Bounded Troughs		— ? — ? BPL? Highlands Member Upper Jeffrey's Village Member		— ? — ? AF Fluvial Mixed Fluvial + Minor Marine	? Uplift	
No More Lateral Displacement	Subsidence of Several Small Subbasins and Uplift of Arches		Lower Jeffrey's Village Member		Dominantly Marine, Lesser Nonmarine		
	Basin Widens During Last Stages of Strike Slip Fault Movement That Influenced Subbasin		Codroy Road Formation SCF				
60 Km Northeastward Lateral Displacement Uplift	Steady Basin Extension	ANGUILLE GROUP	BPL? FCM		AF AF?		— — ? — —
	2nd Basin Pullapart		Spout Falls Formation		Fluvial Rapid Basin Fill	Uplift + Wrench Fault Movements	
	Snakes Bight Fault Active		Friars Cove Formation		Lacustrine-Fluvial-deltaic		Tournaisian
60 Km Northeastward Lateral Displacement Uplift	Steady Basin Extension		Snakes Bight Formation		Lacustrine		
	1st Basin Pullapart		Kennels Brook Formation ? — ? —		Fluvial Rapid Basin Fill	Wrench Fault Movements	— — ? — — Famennian

TABLE 3: Compilation of stratigraphy, sedimentation and inferred tectonic events in the Carboniferous Bay St. George subbasin and surrounding areas.
●● - conglomerate; AF - Alluvial Fan; FCM - Fischells conglomerate member; SCF - Ship Cove Formation; BPL - Brow Pond lentil

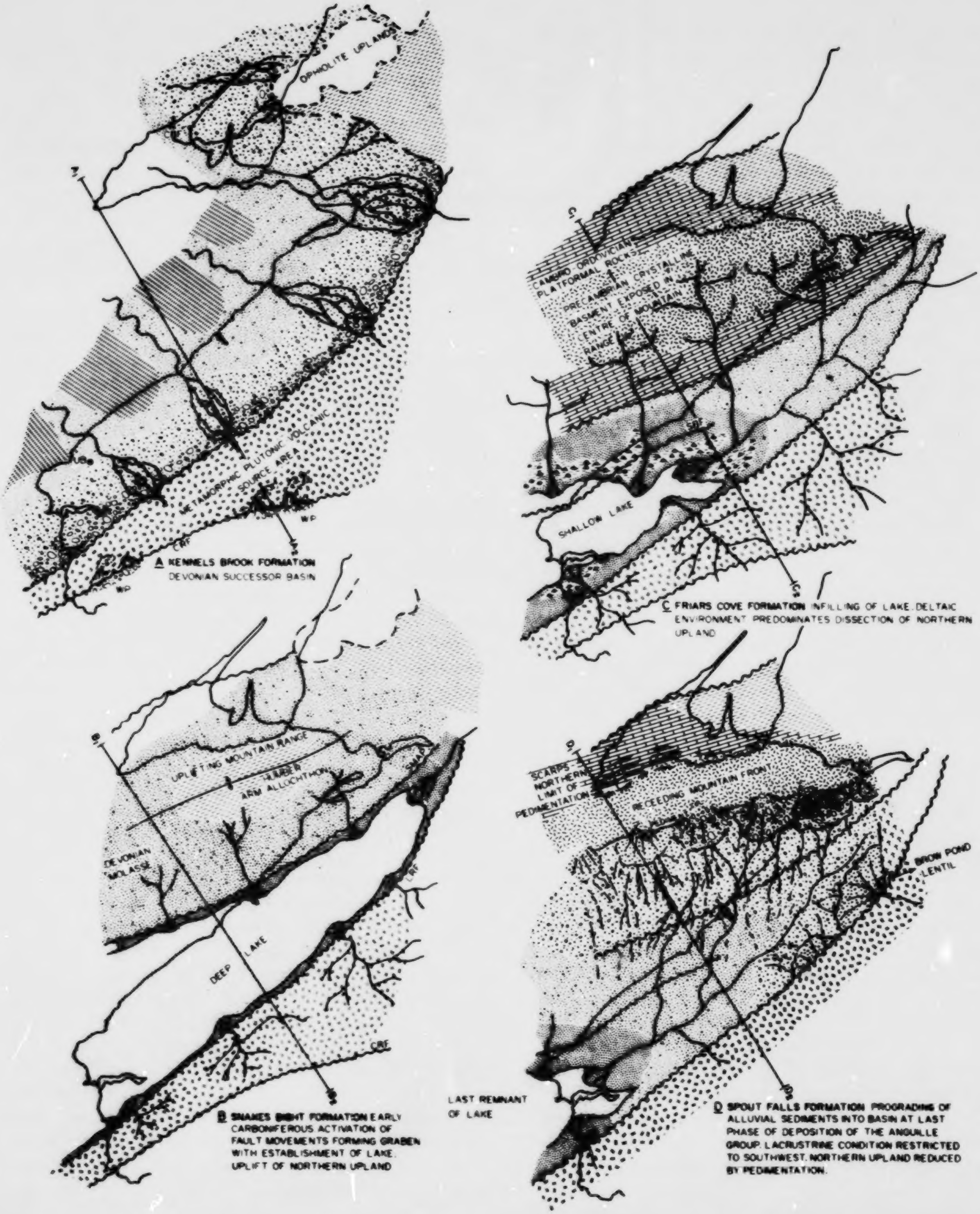
margins and axis. As the lake became infilled, sand-dominated deltas built an extensive plain on which marsh, shallow lacustrine and fluvial subenvironments flourished during the deposition of the Friars Cove Formation. Deltaic and shallow lacustrine conditions persisted in the southwest of the basin until the end of deposition of the Anguille Group. However, fluvial sedimentation predominated to the north and northeast where gray sandstones of the Friars Cove Formation were initially laid down but then gave way upward into redbeds. The latter, which comprise the Spout Falls Formation, were deposited widely in the north-central area of the subbasin by shallow ephemeral and braided streams that constructed a sandy, alluvial plain. Large rivers also crossed the alluvial plain at times to and supplied the contemporary lacustrine deltas to the southwest.

Sandy and gravelly alluvial fans were laid down around the edges of the subbasin. The Fischells conglomerate member in the Flat Bay anticline may have formed as a local fanglomerate in the north of the subbasin. Less likely, they were part of a narrow zone of fanglomerates that may have periodically marked the northwest margin of the subbasin during Anguille Group time. Detritus was derived from the Humber Arm allochthon highlands.

Although sedimentological evidence is not conclusive, dolomites in the shallow and deep lacustrine sequences, and redbeds deposited by ephemeral streams, suggest that the climate was at least semiarid during the evolution of the Anguille Group. Several paleomagnetic studies independently verify that the Maritime provinces were 10° to 20° south of the paleo-equator during the Devonian and Carboniferous (Roy, 1973; Smith et al., 1973; Irving, 1977).

General points of interest in summarizing the paleogeography of the group are: (1) that the thick siliciclastic succession was supplied predominantly with detritus from southeast of the Long Range fault throughout the deposition of the basin fill; (2) evidence for a detrital source north of the subbasin in the Cambro-Ordovician platformal and allochthonous rocks of western Newfoundland is present only in siliciclastics of the Friars Cove and Spout Falls Formations; (3) the subbasin was probably narrow and elongate. If the present distribution of rock units reflects closely their original distribution, a subbasin no more than 30 km wide and 100 km long seems probable; (4) the shape and form of the subbasin was largely controlled by northeast trending faults. These structures included the primordial Long Range fault along the southeast margin of the subbasin, the primordial Snakes Bight fault within the subbasin, and an unnamed fault that formed the northwest margin and is now believed to lie concealed beneath younger Codroy Group strata in St. George's Bay. A buried, west trending fault north of the Anguille Mountains may, however, have originally delineated the northern margin of the subbasin during the accumulation of the Anguille Group (Belt, 1969). Belt rightly favoured this fault because of the great thickness difference between the Anguille Group in the Anguille Mountains and the Fischells conglomerate member in the Flat Bay anticline. It is quite probable, however, that Belt's faults joined with the fault along the northwest margin of the subbasin as a single splay of the Long Range fault. The subbasin, hence, could have evolved in the divergent zone between the two faults (Figure 17A); (5), the basal Ship Cove Formation of the Codroy Group is a regional marker which allows the history of tectonic uplift of surrounding uplands, in particular the Humber Arm allochthon highlands, to be equated with the evolution of the Anguille Group within the subbasin.

Conglomerates containing detritus from the Humber Arm allochthon highlands occur at two main stratigraphic


OPHIOLITE UPLANDS
METAMORPHIC PLUTONIC VOLCANIC SOURCE AREA
LRF
CRF
WP
CAMBRO ORDOVICIAN PLATFORMAL ROCKS
PRECAMBRIAN CRYSTALLINE BASEMENT EXPOSED IN CENTRE OF MOUNTAIN RANGE
SHALLOW LAKE
SDF
UPLIFTING MOUNTAIN RANGE
HUMBER ARM ALLOCHTHON
DEVONIAN MOLASSE
DEEP LAKE
LRF
CRF
LAST REMNANT OF LAKE
SCARPS NORTHERN LIMIT OF PEDIMENTATION
RECEEDING MOUNTAIN FRONT
BROW POND LENTIL

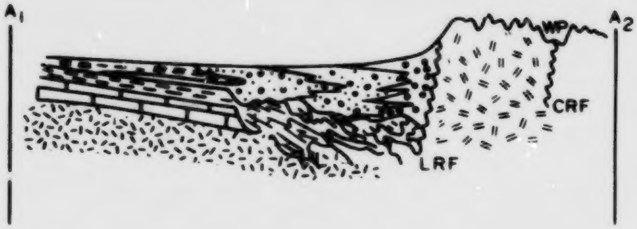
A KENNELS BROOK FORMATION DEVONIAN SUCCESSOR BASIN

B SNAKES BIGHT FORMATION EARLY CARBONIFEROUS ACTIVATION OF FAULT MOVEMENTS FORMING GRABEN WITH ESTABLISHMENT OF LAKE. UPLIFT OF NORTHERN UPLAND

C FRIARS COVE FORMATION INFILLING OF LAKE. DELTAIC ENVIRONMENT PREDOMINATES DISSECTION OF NORTHERN UPLAND

D SPOUT FALLS FORMATION PROGRADING OF ALLUVIAL SEDIMENTS INTO BASIN AT LAST PHASE OF DEPOSITION OF THE ANGUILLE GROUP. LACRUSTRINE CONDITION RESTRICTED TO SOUTHWEST. NORTHERN UPLAND REDUCED BY PEDIMENTATION.

Figure 15: Possible tectono-stratigraphic model for the Bay St. George subbasin during the deposition of the Anguille Group. In this model, the subbasin developed as a narrow graben controlled largely by block faulting within the Cabot Fault system with elevation of uplands both northwest and southeast of the subbasin.



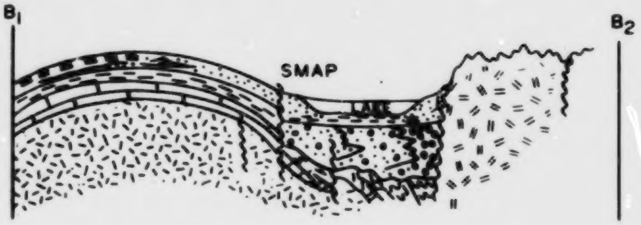
LEGEND FOR FIGURE 15

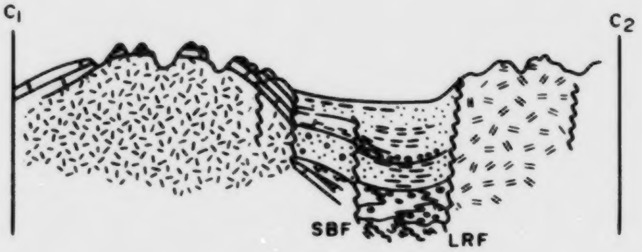
CARBONIFEROUS AND DEVONIAN SEDIMENTS

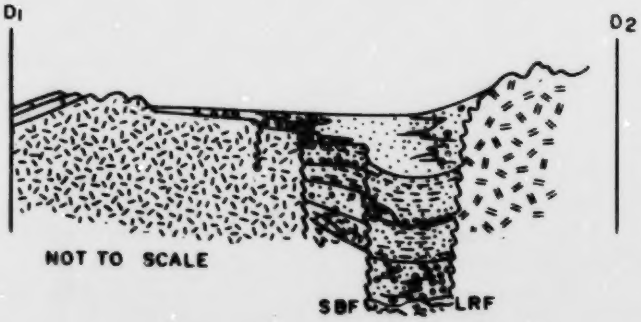
- ▩ FANGLOMERATE FACIES
- ▨ SANDY AND PEBBLY FLUVIAL FACIES
- ▤ FLOOD PLAIN FACIES
- ▒ SANDY DELTA FACIES
- ☐ DELTA PLAIN FACIES
- ▧ LACUSTRINE FACIES

BASEMENT ROCKS

- ✝ ANORTHOSITE
- ░ PRECAMBRIAN CRYSTALLINE ROCKS
- ▦ CAMBRO-ORDOVICIAN SILICICLASTIC AND CARBONATE ROCKS
- ▤ SEDIMENTARY ROCKS OF HUMBER ARM ALLOCHTHON
- ▒ DEVONIAN MOLASSE
- ▨ PRECAMBRIAN TO ORDOVICIAN CRYSTALLINE METAMORPHIC AND VOLCANIC ROCKS







U B - UNION-BRINEX DRILL HOLE
CBF - CLAM BANK FORMATION
WP - WINDSOR POINT GROUP
LRF - LONG RANGE FAULT
CRF - CAPE RAY FAULT
SBF - SNAKES BIGHT FAULT
SMAP - SOUTHERN MARGIN OF APPALACHIAN PLATFORM
$A_1 - A_2$ SECTION

intervals and in widely separate geographic locations. The first and older conglomerates are found at the base of the Friars Cove Formation and can be traced along the northwest limb of the Anguille anticline as thin beds in dominantly gray, fluvial sandstones. Nowhere are they as thickly bedded, coarse and full of Cambro-Ordovician carbonate and siliciclastic pebbles as at Cape Anguille in the extreme southwest of the subbasin. Even allowing for resedimentation of the Cape Anguille conglomerates from margin to axial region of the narrow basin, these deposits are clearly proximal and must have once lain close to a rugged upland adjacent to their present geographic position. This must imply that either (1) Cambro-Ordovician rocks extended southwestward from the Port au Port Peninsula to cover most of the area now occupied by St. George's Bay, a distance of 50 km, or (2) that the source rocks have moved by as much as 95 to 120 km by right lateral, strike-slip fault movements after the Cape Anguille conglomerates were laid down.

The second major conglomerate sequence, the Fischells conglomerate member, includes some of the youngest rocks of the Anguille Group and it is geographically restricted to the north of the subbasin. The conglomerates are clearly proximal and are interpreted to have been deposited upon an alluvial fan that must have once been rooted against the northwestern upland. Since the conglomerates lie unconformably upon Precambrian crystalline basement, it appears that either (1) the Lower Paleozoic supracrustals were already eroded from the area by late Anguille times or (2) the conglomerates were deposited upon a foundering block of previously uplifted basement along the southeastern margin of the highlands which shifted northeastward some 60 km after the conglomerates were deposited. The latter interpretation implies a major episode of wrench movements in late Anguille - early Codroy times.

Two tectono-sedimentary models are thus possible for subbasin evolution during the deposition of the Anguille Group. The first model involves the development of a simple graben-horst rift system (Figure 15) which was activated after thick Devonian molasse was laid down in a broad successor basin. In this model, the graben formed due to extension, block faulting and crustal thinning. Mountains were uplifted southeast of the Long Range fault and northwest of the subbasin. Tilting of the Clam Bank Formation at the west end of the Port au Port Peninsula possibly occurred during this event.

Uplift was followed by denudation of both the poorly consolidated Devonian molasse and the underlying Lower Paleozoic rocks of the Humber Arm allochthon highlands to provide detritus for the Snakes Bight Formation. Conglomerates rich in large pebbles of carbonate, quartzite, mafic volcanics and granites derived from erosion of the Lower Paleozoic strata, and Grenvillian basement in the highlands, reached the subbasin at the beginning of the Friars Cove Formation. The upland was gradually reduced in elevation and areal extent. The southeastern margin of this west trending mountain ridge would have lain close to a fault that is postulated to strike southeast beneath St. George's Bay from the vicinity of the Flat Bay anticline (see SMAP on Figure 15). The mountain front retreated northward in the semiarid climate due to pedimentation so that, by late Anguille times, conglomerates were deposited upon Precambrian crystalline basement at Flat Bay, north of which they thinned rapidly. Consequently, by the commencement of Codroy deposition, the mountains were reduced to a relatively low-lying ridge (hereafter called the Port au Port ridge), onlapped by flat-lying, thin, Codroy Group strata (Figure 15).

The second model assumes that the subbasin and surrounding uplands were fashioned by major, right-lateral, strike-slip movements related to the development of the Cabot Fault system (Figure 16). The Deer Lake Basin also formed within this fault system and has been accredited an early, wrench-fault history by Hyde and Ware (1981).

A brief introductory discussion of wrench-fault systems will aid in assessing the history of the subbasin within such a system. Faults in such systems are commonly long, relatively straight and in many cases bend, splay and braid locally. Numerous minor faults trend and splay parallel or subparallel to the main wrenches but cross-faults are also prominent. Compressional and extensional stresses both occur between fault splays, braids and bends of the fault system. Significantly, this means that uplift and subsidence of fault-bounded blocks and wedges may occur concurrently or intermittently and over widely spaced distances along the system (Crowell, 1974a; Reading, 1980). Lateral displacement may reach several hundred or more kilometres. Much of this movement is accommodated by displacements of a lower order of magnitude on the constituent faults in the system (Crowell, 1974a). Synthetic and antithetic faults can have different displacement vectors and folding commonly occurs in association with these structures. The locus of movement may shift from one fault to another with time. Depositional basins form along or between one or more wrench-faults where they bend, splay or lie parallel to one another. These include pull-apart basins at bends or splays, depressions at fault bends and where crustal stretching occurs, and wedge-shaped basins between divergent faults (Crowell, 1974b). Basin-fills are often very thick and frequently show systematic changes in thickness and age of sedimentary fill revealing how the basins evolved. (Crowell, 1974b, 1979; Reading, 1975, 1980; Steel, et al., 1977; Steel and Aashiem, 1978; Bluck, 1978, 1980).

Figure 16 displays the present-day distribution of faults, geologic terranes and Carboniferous sedimentary basins associated with the Cabot Fault system. It clearly shows many features of a strike-slip system as previously indicated by Belt (1969). Faults are long and straight but they bend locally and there are numerous fault splays. The associated basins are long and narrow and contain thick basin-fills, some of which were deformed between episodes of sedimentation, as, for example, the Anguille Group in the Deer Lake Basin (Hyde and Ware, 1980, 1981). Although deformation did not interrupt sedimentation in the Bay St. George subbasin, the thickness and distribution of rock units in the Anguille Group shows a systematic change from southwest to northeast. In the southwest, the succession consists of 3200+ m of Kennels Brook Formation overlain by 1600 m of Snakes Bight and Friars Cove Formations immediately below basal Codroy limestones. In the north of the Anguille Mountains, the succession is dominated by the younger Friars Cove and Spout Falls Formations. These formations have an accumulative thickness of at least 3500 m, overlying perhaps 1000 m of Snakes Bight Formation and an unknown thickness, if any, of Kennels Brook Formation. This suggests that two basin-fills occur. The older basin-fill was restricted to the southwest of the subbasin and was dominated by the Kennels Brook Formation. The younger basin-fill, composed mostly of strata of the Friars Cove and Spout Falls Formation, lay northeast of the first which it also partly overlapped.

Circumstantial evidence that supports the wrench tectonic origin for the Bay St. George subbasin includes:

(1) the northeastward displacement of the Humber Arm allochthon highlands by at least 120 km prior to the deposition of early Codroy Group strata;

(2) the deposition of thick Carboniferous sedimentary sequences in narrow basins, implying not only substantial subsidence but adjacent uplift of source areas. These uplands persisted and continued to

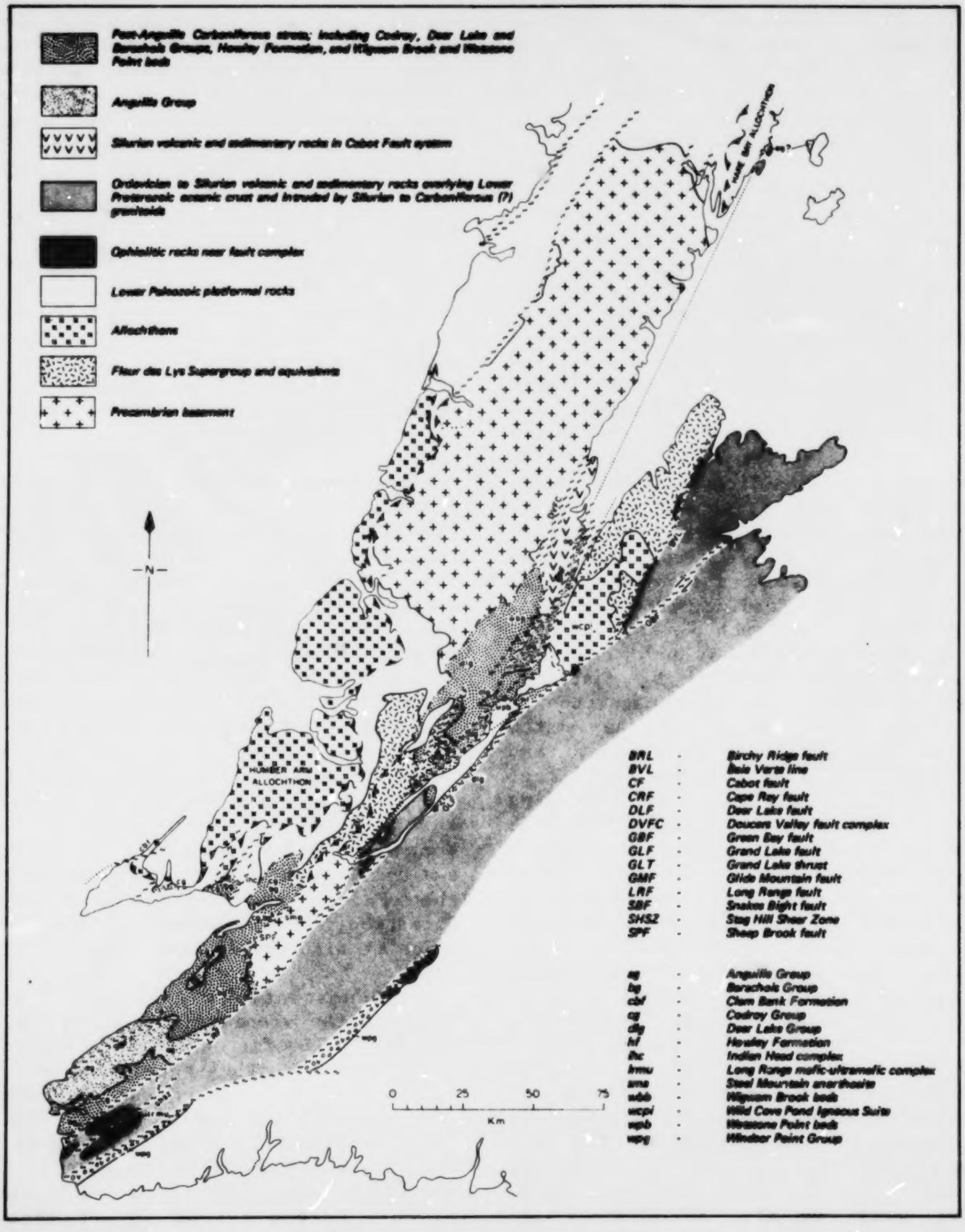

Post-Anguille Carboniferous strata; including Codroy, Deer Lake and Barachois Groups, Howley Formation, and Wigwam Brook and Wetstone Point beds
Anguille Group
Silurian volcanic and sedimentary rocks in Cabot Fault system
Ordovician to Silurian volcanic and sedimentary rocks overlying Lower Proterozoic oceanic crust and intruded by Silurian to Carboniferous (?) granitoids
Ophiolitic rocks near fault complex
Lower Paleozoic platformal rocks
Allochthons
Fleur des Lys Supergroup and equivalents
Precambrian basement
N
HARE BAY ALLOCHTHON
HUMBER ARM ALLOCHTHON
WCPI
0 25 50 75
Km
BRL - Birchy Ridge fault
BVL - Baie Verte line
CF - Cabot fault
CRF - Cape Ray fault
DLF - Deer Lake fault
DVFC - Doucers Valley fault complex
GBF - Green Bay fault
GLF - Grand Lake fault
GLT - Grand Lake thrust
GMF - Glide Mountain fault
LRF - Long Range fault
SBF - Snakes Bight fault
SHSZ - Stag Hill Shear Zone
SPF - Sheep Brook fault
ag - Anguille Group
bg - Barachois Group
cbf - Clam Bank Formation
cg - Codroy Group
dlg - Deer Lake Group
hf - Howley Formation
ihc - Indian Head complex
lrmu - Long Range mafic-ultramafic complex
sma - Steel Mountain anorthosite
wbb - Wigwam Brook beds
wcpi - Wild Cove Pond Igneous Suite
wpb - Wetstone Point beds
wpg - Windsor Point Group

Figure 16: Main faults, distribution of geologic terranes and Carboniferous sedimentary basins associated with the Cabot Fault system in western Newfoundland. Based on geologic map of Newfoundland (Williams, 1967); modified with data from Knapp et al. (1979), Hyde and Ware (1980, 1981), Chorlton and Dingwell (1981), Smyth and Schillereff (1982), Hyde (personal communication, 1981, 1982), Hibbard (personal communication, 1981) and Knight (this report).

supply detritus to the subbasin throughout Friars Cove and Spout Falls time;
(3) the deposition and deformation of the Anguille Group in the Deer Lake Basin prior to the deposition of the Viséan Deer Lake Group (Hyde, in press; Hyde and Ware, 1981);
(4) the distribution of lithofacies and formations in the southern Anguille Mountains as compared to those in the north of the mountains. This indicates that the locus of deposition shifted northeastwards with time. The subbasin probably extended in a southwestward direction and it is most readily explained as a pull-apart basin (cf. Bradley, 1982). Considerable thickening of the Anguille Group southeastward across the Snakes Bight fault demonstrates that it was probably an active growth fault at least during deposition of the Friars Cove and Spout Falls Formations;
(5) right-lateral, post-350 Ma wrench movements have also been proposed along the Green Bay fault (Hibbard, personal communication, 1981). This fault offset the Baie Verte line, probably in the Early Carboniferous, since flat-lying, possibly Pennsylvanian conglomerates are inferred to lie in depositional contact with the same structure (Hibbard, personal communication, 1981). Wrench movements in the central Newfoundland uplands have also been postulated to offset the limbs of a major Acadian syncline across the Green Bay fault by some 20 km of right-lateral displacement (Upadhyay, 1973).

The margins of the subbasin during deposition of the Anguille Group are not easily defined. The main structural feature of the area is of course the Long Range fault which was probably the southeast margin of the subbasin at this time. This fault is believed to have accommodated most of the wrench movements that created the subbasin, although it is clear from sediment provenance studies in the Anguille Group that substantial uplift also occurred southeast of the fault.

The northern and northwestern margins of the subbasin were formed by a right-lateral curved splay of the Long Range fault as discussed above. The splay (Figure 17A on foldout B), which was later covered by strata of the Codroy Group, likely had a complex history. The fault provided the locus upon which basin pull-apart occurred and displaced terranes moved. The occurrence of an older and a younger basin-fill sequence in the Anguille Group suggests that the fault was the northern basin margin in the Late Devonian and again in the Early Mississippian. If both basin-fills were associated with the splay fault, then clearly the older sequence was subsequently displaced some 20 km to the southeast of the original boundary. A west trending magnetic lineament (Geological Survey of Canada, 1971) that is located about 20 km south of the postulated splay fault may well represent the subsurface expression of the northern margin of the first pull-apart basin (Figure 17A). Toward the end of the depositional history of the Anguille Group, however, the curved splay fault is believed to have straightened so that it extended northeastward to cut the Steel Mountain anorthosite. Consequently, basin pull-apart was to cease gradually during the early stages of deposition of the Codroy Group because of the straightening (Lensen, 1958). This is perhaps reflected in the change of subbasin width and shape that occurred during the first phases of Codroy sedimentation.

The southwest margin lies somewhere beneath the Gulf of St. Lawrence. It may coincide with a nearly north trending ridge of pre-Carboniferous rocks that Howie and Barss (1975a) show 15 km offshore of Cape Anguille (see Figure 17A and B); they show the ridge as covered by thinned Carboniferous cover.

In the wrench-fault model, two major pulses of basin extension probably occurred during deposition of the Anguille succession (see Figure 17A and B). The first pulse created the pull-apart basin into which the thick Kennels Brook Formation accumulated. This early-stage basin was probably limited by (1) the southwestern basement ridge of Howie and Barss (1975a) and (2) a west trending fault now delineated by the west trending magnetic lineament (Figure 17A). The distribution of the upper 1000 m of the Kennels Brook Formation north of this lineament suggests that basin subsidence and extension continued gradually so that the first-pulse margin in the north of the basin was overstepped by the Devonian sediments.

A second pulse of accelerated subsidence and extension then occurred in the pull-apart basin to create a new depository northeast of the first. Deposition of the 3500+ m succession of fluvial Friars Cove and Spout Falls sediments followed. The northern basin margin probably coincided with the west trending fault postulated by Belt (1969, see his Figure 1) to the north of the Anguille Mountains. Eventually upper Anguille strata overstepped this margin northeastward (Figure 17B on foldout B) along the subbasin axis so that a thin succession of upper Anguille sediments covered basement before the deposition of a thick, basin-fill sequence belonging to the Codroy Group (Figure 17B).

A synopsis of the basin development may thus be summarized within the wrench model (Table 3) as follows:

1. Commencement of dextral wrench movements in the Devonian on the Long Range fault and other faults of the Cabot Fault system.
2. A pull-apart or wedge basin developed at a bend or splay of the Long Range fault southeast of the Steel Mountain anorthosite. The first pulse of basin pull-apart was followed by gradual basin extension so that deposits of the Kennels Brook Formation overstep the northern boundary of the subbasin.
3. Uplift of the Humber Arm allochthon highlands led to the formation of a narrow, deep water, lacustrine basin in which the Snakes Bight Formation was deposited.
4. Basin extension accelerated during a second pulse of basin pull-apart. The Humber Arm allochthon highlands moved northeastward over a distance of some 60 km during the second phase of basin extension.
5. Fault blocks foundered locally in the northeast of the basin toward the end of Anguille sedimentation. Northeastward displacement of the Humber Arm allochthon highlands continued for perhaps a further 60 km before or during the early Viséan. Deformation of the Anguille Group is minimal because the subbasin lay between divergent faults and pull-apart caused extension rather than compression (Crowell, 1974a and b).

This model of basin extension resembles that proposed for Upper Old Red Sandstone strata of the Midland Valley of Scotland by Bluck (1980) and the Devonian Hornelen Basin of Norway (Steel et al., 1977; Steel and Aashiem, 1978). It is also favoured for the Bay St. George subbasin by Belt (personal communication, 1981) who first suggested the idea to the author.

Interpretation of the evolution of the subbasin within a major dextral wrench fault system contradicts recent models based upon paleomagnetic data that suggest the Devonian-Carboniferous faults of Maritime Canada including the Cabot Fault system were part of a large scale sinistral wrench system (Kent and Opdyke, 1978 and 1979; Irving, 1979). The data presented here in a local study, however, supports the broad regional conclusions of a right-lateral, wrench-fault history for the Maritimes Basin during the Devonian and Carboniferous as suggested by Bradley (1982).

Part 3 Codroy Group

Introduction and Definition

The Codroy Group is a mixed sequence of marine and nonmarine strata, 4000-6000 m thick, that includes siliciclastic, evaporitic and calcareous sedimentary rocks. Previous studies (Hayes and Johnson, 1938; Bell, 1948; Riley, 1962; Baird and Cote, 1964; Belt, 1969; Table 1) did not attempt to define a lithostratigraphy for the group, except in a very general way, and little attempt was made to correlate rock sequences from various parts of the subbasin.

The Codroy Group is defined here to include all rocks between a basal limestone, the Ship Cove Formation, and the first continuous deposits of fining-upward, coarse grained, gray, arkosic sandstones and red siltstones, the Barachois Group. Similar fining-upward sequences also occur in the upper part of the Codroy Group but at this stratigraphic horizon they are locally intercalated with marine beds and limestones. The upper contact is difficult to define accurately because of poor exposure and faulting, but it is probably both gradational and diachronous. Basal strata of the Codroy Group lie with apparent conformity upon the underlying Anguille Group at most localities in the Bay St. George subbasin. In places, the Ship Cove limestone does not form the local base of the Codroy succession. Instead, younger, undivided strata rest unconformably on Precambrian or Lower Paleozoic basement (e.g., along the east margin of the Indian Head Complex) and in isolated pockets in a number of places along the south side of the Port au Port Peninsula.

Four formations, the Ship Cove, Codroy Road, Robinsons River and Woody Cape Formations, are formally proposed for the group (Table 4). The divisions are based upon lithological criteria and are supported by paleontological control where possible. The Robinsons River Formation is subdivided into four members: the Jeffrey's Village, Highlands, Mollichignick and Overfall Brook Members. Correlation of rock units is shown in Table 4. Biostratigraphical control within the Codroy Group has previously followed Bell's (1929) A to E subzones of the Windsor Group in Nova Scotia (Hayes and Johnson, 1938; Bell, 1948; Table 4 and 10). The zones have been extensively applied in the Maritimes Basin (Stacy, 1953; Sage, 1954; Kelley, 1967b; Moore, 1967, Moore and Ryan, 1976.) They are being refined by further macrofaunal, microfaunal and microfloral studies. In the Bay St. George subbasin, this work includes macrofaunal studies by McGlynn (personal communication, 1978), microfaunal studies by Mamet (1968), von Bitter (1975), and von Bitter and Plint-Geberl (1978, 1979, 1982) and investigations of miospores by Utting (personal communication).

Only the basal Ship Cove Formation and the succeeding Codroy Road Formation maintain continuity throughout the subbasin. Major faults interrupt the succession near the top of the Codroy Road Formation. Poor exposure also means that and the exact inter-relationships of the remaining formations and members are incompletely understood.

Distribution

The Codroy Group underlies two extensive areas of the subbasin (Figure 4). The main exposures occur in the St. Georges Bay lowlands north of the Anguille Mountains where rock units include the Ship Cove and Codroy Road Formations, the Jeffrey's Village and Highlands Members of the Robinsons River Formation, and the Brow Pond lentil.

The Codroy Group, however, also occupies much of the Codroy lowlands southeast of the Anguille Mountains. There it includes the Ship Cove and Codroy Road Formations, the Jeffrey's Village, Mollichignick and Overfall

TABLE 4 - LITHOLOGIES AND DEPOSITIONAL ENVIRONMENTS OF FORMATIONS OF THE CODROY GROUP

NEVES et. al., 1972	UTTING 1978	MAMET 1970 1968	BELL 1929 1948	CODROY LOWLANDS COASTAL SECTION		CODROY LOWLANDS INLAND AREAS		ST. GEORGE'S BAY LOWLANDS	
Mio-spore Zones		Fora-mini-fera Zones	Macro-Faunal Sub-zones						
NC	ASSEMBLAGE II	17	E			ROBINSONS RIVER FORMATION		ROBINSONS RIVER FORMATION	
				Lithology	Environment	Lithology	Environment	Lithology	Environment
						OVERFALL BROOK MEMBER			
				WOODY CAPE FORMATION		Red arkosic sandstone, minor conglomerate, some fine gray beds, gray pebbly mudstones	Humid alluvial fan, braided stream		
		16_s	D	Green-gray mudstone and siltstone, micaceous and arkosic sandstones; black carbonates and shale, fossiliferous	Delta complex: shallow bay, delta top, delta channel, prodelta muds	Disconformable?			
						MOLLICHIGNICK MEMBER			
VF						Red siltstone and sandstone, gray micaceous and arkosic sandstone, gray and red muddy, pebbly sandstones and conglomerate, gray mudstones and dolomites, fossiliferous carbonates, caliche limestone	Alluvial deposits: River channel, overbank, alluvial fan; Shallow lacustrine Shallow marine; Pedogenic carbonate	HIGHLANDS MEMBER	
		16_i	C					Red and minor gray, yellow sandstone, red siltstone, minor conglomerate. Some caliche, limestone	Alluvial deposits: meander river, overbank, alluvial fan to east and north; Some aeolian sands; Possibly marine at base
								Conformable	
								JEFFREY'S VILLAGE MEMBER	
NM	ASSEMBLAGE I	15	B	JEFFREY'S VILLAGE MEMBER				Red siltstone, fine red sandstone, gray sandstone; gray shale and marine sandstone, fossiliferous and algal carbonates; gray mudstone, shale, sandstone; gypsum, anhydrite, halite, potash salts	Distal alluvial plain, shallow streams, playa flats; Shallow lagoon and marine shelf, algal banks; Deltas; Hypersaline lagoon, salinas, mud flats
				Red siltstone and brecciated limestones	Shallow shoreline and distal alluvial plain				
				Conformable				Contact covered	
				CODROY ROAD FORMATION					
				Black carbonates, gray shale and mudstone, gypsum/anhydrite, red siltstone and thin sandstone	Marine shelf and lagoon, hypersaline lagoon and mudflats, alluvial plain	Biohermal limestone, gypsum, red siltstone, gray mudstone and black carbonate	Open marine, reefs, hypersaline lagoon, alluvial plain and playa flat	Biohermal limestone and gypsum-anhydrite, gray shales and evaporitic mudstones replaced northward by gypsum and anhydrite	Reefs, hypersaline shallow lagoon, sabkha flat
			A	SHIP COVE FORMATION					
				Lithology		Environment			
				Laminated limestone, shaly limestone, gypsiferous, some oolitic and oncolitic units, limestone breccia, minor sandstone, gray, green and red shale		Shallow subtidal to intertidal carbonate flat		General continuity throughout basin except near Fischells Brook where deposits of gray shale and thin sandstones are associated	

Brook Members of the Robinsons River Formation and the Woody Cape Formation. Basal Codroy strata occur in fault zones and in synclinal folds within the Anguille Mountains.

Description of Formations

Ship Cove Formation

Definition and distribution

The Ship Cove Formation is the name given to a widespread and uniform deposit of limestone that forms the basal unit of the Codroy Group. The unit was originally called the Ship Cove limestone and was named after Ship Cove (Bell, 1948) on the northwest flanks of the Anguille Mountains. The type section occurs at the falls near the mouth of Ship Cove Brook. It is also well exposed on Codroy Island, in many streams that cross the flanks of the Anguille Mountains and Bald Mountain, and in tight synclinal folds within the Anguille Mountains. The formation is folded around the Flat Bay anticline, outcropping along Fischells Brook and Northern Feeder. It is also recorded in drill holes penetrating gypsum deposits at Flat Bay (McKillop, 1959), Heatherton (Rose, 1947), and near Highlands River (McKillop, 1953a). Baird (1949) records limestone float along Coal and Sheep Brooks near the Steel Mountain anorthosite. Along the northern margin of the subbasin, it is exposed on Romaines Brook and was intersected by drill holes at the base of the Romaines gypsum deposit (McKillop, 1959). A similar limestone near Boswarlos and shelly limestones at Aguathuna on Port au Port Bay are also correlated with the Ship Cove Formation (von Bitter and Plint-Geberl, 1982).

The Ship Cove Formation sharply and conformably overlies sandstones of the Friars Cove Formation and Spout Falls Formation in the Anguille Mountains and Bald Mountain. At Fischells Brook, it lies conformably upon sandstones and conglomerates of the Fischells conglomerate member. This abrupt change from coarse siliciclastic rocks to laminated limestone across the contact suggests the contact may be a disconformity in the north of the subbasin. The basal contact on Codroy Island is, however, gradational; Ship Cove limestones are interbedded with sandstones of the Friars Cove Formation.

The upper contact of the Ship Cove Formation is mostly covered, but in section K295 and K214 (Figure 18) and in drill logs (Smith, 1953; McKillop, 1959), it appears to be conformable and sharp with the overlying Codroy Road Formation. The formation is overlain by red siltstones in the south of the subbasin but by gray shales and gypsum north of the Anguille Mountains. At Fischells Brook and in drill logs at Heatherton (Rose, 1947) it appears to grade up into gypsum and thin gray shales, but has been replaced by growth of displacive gypsum at Flat Bay and Romaines Brook (McKillop, 1959).

Thickness

The formation is fairly uniform in thickness, averaging 18 to 20 m. It may, however, be somewhat thinner in the southwest of the Anguille Mountains where only 13 m was measured in section K295 (Figure 18). On Fischells Brook, approximately 22-25 m is exposed, yet just 8 km to the north in the Flat Bay gypsum mine, drill holes penetrated only 5.7 m beneath gypsum (McKillop, 1959); approximately 8 m was recorded in drill holes near Heatherton (Rose, 1947). Thicknesses at Romaines Brook from outcrop and drill hole information (McKillop, 1959) vary between 2 and 11 m; 2 to 4 m occurs in equivalent strata on the north side of the Port au Port Peninsula.

General lithology

The Ship Cove Formation is composed of well laminated, gray limestones that become shalier upward where they contain numerous gypsum molds. The succession is generally consistent throughout the Anguille Mountains but differences occur in the north and south of the subbasin (Figure 18).

In the Fischells Brook area, shales and thin sandstones are interbedded with the limestones at the base of the formation (Figure 18). Belt (1969) separated this basal shale from the Ship Cove Formation. Fossils are also more common in the north of the subbasin and include small, whole, smooth-shelled brachiopods (possible *Composita*, cf. Moore and Ryan, 1976). Conodonts occur throughout the 3 m section at Romaines Brook, although they are restricted to the basal few centimetres in other sections of the formation (von Bitter and Plint-Geberl, 1982).

On Codroy Island in the south, well sorted gray sandstones and intraformational limestone breccias, not found elsewhere in the subbasin, occur interbedded with the limestones (Figure 19). Synsedimentary deformation of the limestones is also seen on the island.

Different sections contain minor deposits of oolitic limestone, massive limestone, thin gray-green shales, red mudstone and fine gray sandstone beds or laminae. Seven lithofacies are defined from field and petrographic data. In field sections, the lithofacies are generally arranged in a vertical sequence in which facies A is overlain by B which is in turn overlain by C. This sequential order was observed by the author in the Macumber Formation at Whycocomagh, Cape Breton and it was also stressed by Geldsetzer (1978) in his interpretation of the basal Windsor limestone. The lithofacies (Table 5), are as follows: (A) stratified packstone lithofacies; (B) laminite lithofacies; (C) moldic, argillaceous and shaly laminite lithofacies; (D) intraformational limestone-breccia lithofacies; (E) oolitic limestone lithofacies; (F) sandstone lithofacies and (G) other rock types.

(A) STRATIFIED PACKSTONE LITHOFACIES

Description of lithofacies A: In most localities, lithofacies A forms the basal 20-175 cm of the formation; 5 to 40 cm thick units also occur higher in the formation within laminated limestones. The packstones generally form less than 5% but locally 15% of the formation. The facies is made up of undulose, 1-5 cm thick layers of buff to pale gray weathering, blue-black, structureless packstones and wackestones which are separated by millimetre thick laminations of lime mudstone.

Large, straight, widely spaced, low amplitude ripple-marks occur at Ship Cove (Plate 31). The ripple crests trend 230° and are composed of size-sorted carbonate granules; troughs consist of fine lime sand. Horizontal, randomly orientated trails occur on basal bedding surfaces in the facies along Fischells Brook, Highlands River and Northern Feeder. The packstones and wackestones (Dunham, 1962) consist of generally poorly sorted, sand to fine, pebble-size grains which include mostly pellets and peloids (Plate 32) (Bathurst, 1975). Rounded to angular intraclasts, oncolites, aggregates, some ooids and rare fossil debris are also present. The latter is most common in the north of the subbasin; articulate brachiopods, ostracods, fish scales, broken tubular bryozoa and calcispheres are commonly found. The calcispheres, which have not been observed south of K179 (Figure 18) except at Ryans Brook, consist of structureless spheres of single calcite crystals and of solitary and colonial 'coccoid-like' spheres (Plate 33). The latter have a fine, tangential, wall structure (possibly a calcitized sheath). Serpulid worm tubes, possible gastropods and fragmented ostracods occur in the facies 2 km upstream from the road bridge at Ryans Brook. Packstones at the bridge itself, however, lack any skeletal fragments. Scattered terrigenous silt and carbonaceous material occurs in the limestones in general.

TABLE 5 COMPILATION OF AVAILABLE GEOLOGICAL DATA FOR THE SHIP COVE FORMATION

	SW	SOUTHERN ZONE HIGH INTERTIDAL		CENTRAL ZONE SUBTIDAL TO INTERTIDAL TO HIGH INTERTIDAL								NORTHERN ZONE NE MARINE DOMINATED SUBTIDAL TO LOW INTERTIDAL					
Facies Structures Fauna		Codroy Island	K 56	Ryans Brook	K 214	K 275	K 340	K 288	Sandy's Pool	K 178	K 178	Ship Cove	Highlands River	Northern Feeder	Fishels River East Cobbs Pool	Fishels River West	Port au Port
Facies F Sandstone		X				X								X	X	X	
Facies D Limestone breccia		X															
Facies E Oolitic limestone												X		X	X		
Facies G Gray shale, red siltstone					X^{Rd}				X^{Gy}					X^{Gy}	X^{Gy}	X^{Gy}	
Facies C Mottled argillaceous and shaly laminite		X		X	X	X			X	X	X	X	X				
Structures in Facies C	Mudcracks								/								
	Ripple drift											/	NO INFORMATION				
	Stromatolites			/					/								
	Pellet packstone				/	/			/								
Facies B Laminite		X	X	X	X	X	X			X	X	X		X	X	X	
Type 1 Light and dark colored					/	/	/	/	NO INFORMATION	/	/						
Type 2 Silty		/	/		/	/						/					
Type 3 Fenestral			/		/	/						/		/	Poor in Fenestra		
Structures in Facies B	Mudcracks	/	/									/					
	Gypsum						/								/		
	Deformation (Tepee, etc)	/	/		/	/		/				/				/	
	Stromatolites	/	/		/					/							
	Ooids		/														
	Fossils														/		
	Calcispheres														/		
	Trace fossils														/		
	Cements														/		
Facies A Pellet or skeletal packstone				X	X	X	X	X			X	X	X	X	X	X	X
Structures in Facies A	Oncolites			/	/			/			/	/	/	/	/	/	/
	Intraclasts											/					
	Ooids														/	/	
	Fossils			/							/	/	/	/	/	/	/
	Trace fossils												/	/	/		/
	Cements			/							/		/		/	/	
Sedimentary rocks overlying formation			Red Siltstone		Red Siltstone							Gray Shales	Gray Shales			Gypsum & Limestone	
Facies at base of formation		B	B	A	A	A (Thin)	A	A		B or C	A	E or A	A	A	A	A	A
Base type overlying red (Rd) or gray (Gy) sandstone or conglomerate of Anguille Group		Gradational Slt Gy	Sharp Slt Gy	Sharp Slt Gy	Sharp Slt Gy	Sharp Slt Gy	Sharp Slt Gy	Sharp Sltst Gy		Sharp Slt Rd Gy	Sharp Slt Gy & Rd	Sharp Slst Rd	Sharp Slt Rd	Sharp Cg. Slt. Gy	Sharp Cgl. Slt. Gy	Sharp Cgl. Slt. Gy	Sharp Cgl. Gy

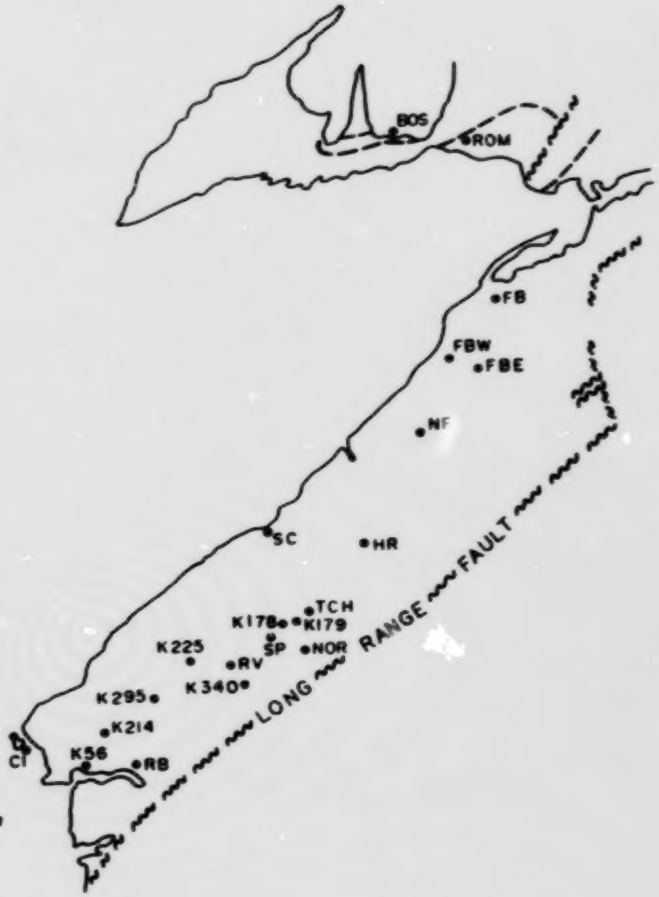
LEGEND for Figure 18

CI	CODROY ISLAND
RB	RYANS BROOK
RV	ROUND VALLEY
SP	SANDY'S POOL
NOR	NORANDA SHOWING
TCH	TRANS CANADA HIGHWAY
SC	SHIP COVE
HR	HIGHLANDS RIVER
NF	NORTHERN FEEDER
FBW	FISCHELLS BROOK WEST
FBE	FISCHELLS BROOK EAST
FB	FLAT BAY QUARRY
ROM	ROMAINES BROOK
BOS	BOSWARLOS

Moldic laminite
Shaly limestone
Laminite
Packstone
Sandstone
Shale
Conglomerate

Red Siltstone
Sandstone
Shale
Limestone

FC	Flute Cast
LC	Load Cast
BM	Brush Mark
ST	Stromatolite
--.---	Intraclasts
⊙	Oncolites
•˙•	Pellets, ooids
⌒	Fossils
	Ostracods
	Brachiopods
§	Bioturbation
◇◇	Molds after gypsum
	Fenestral porosity
	Mudcracks
	Fractures, silt-filled cracks deformed by compaction
	Tepee Structures
	Deformed bedding or lamination
	Ripple cross-lamination
	Lamination - planar or wavy
	Crossbeds
→	Current direction
—+—	Crest of symmetrical ripple mark
↔	Parting lineation



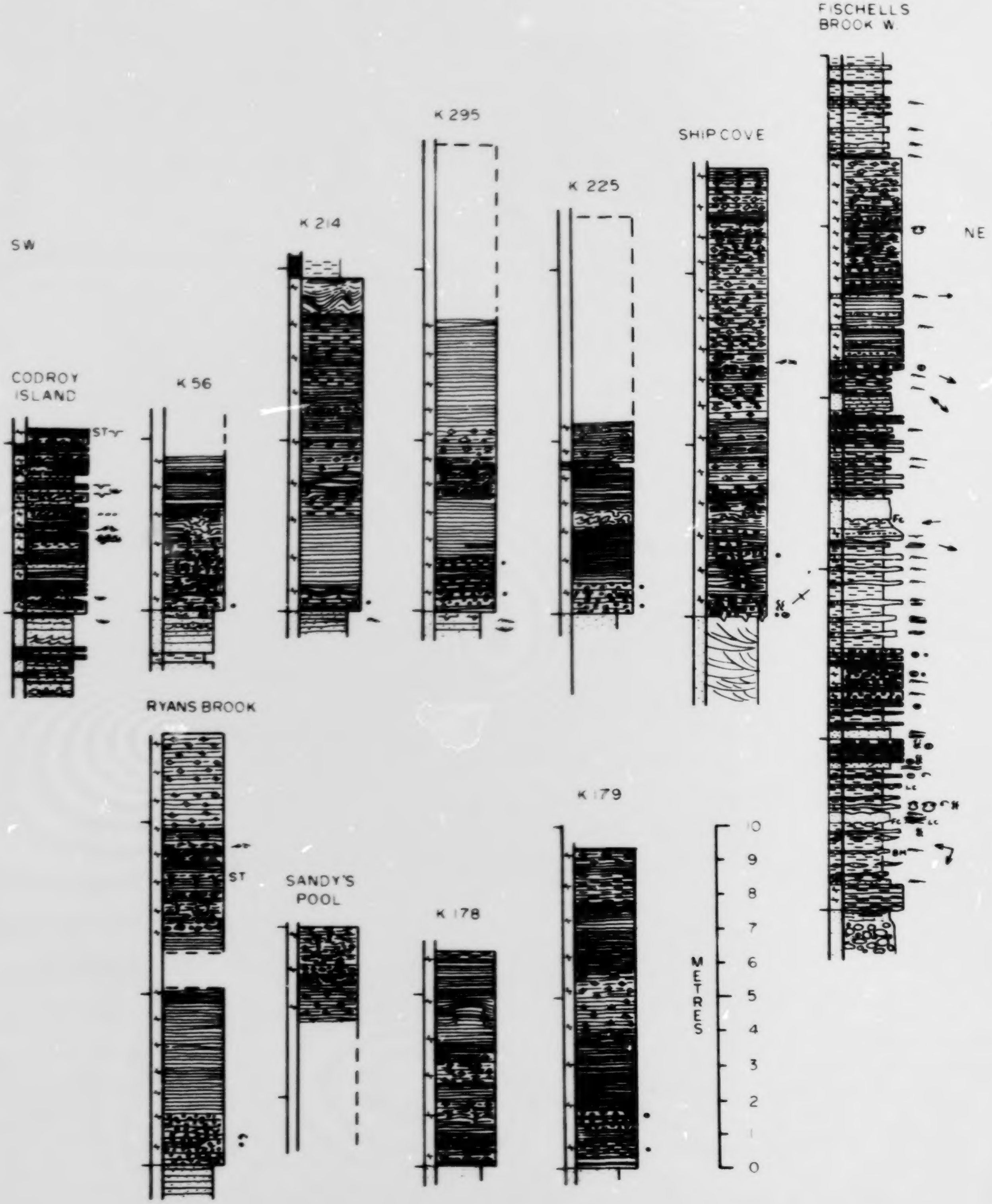

FISCHELLS BROOK W.
K 295
SHIP COVE
K 225
K 214
SW
NE
CODROY ISLAND
K 56
ST
Fc
Bm
RYANS BROOK
ST
SANDY'S POOL
K 178
K 179
10
9
8
7
6
5
4
3
2
1
0
METRES

Figure 18: Sections through the Ship Cove Formation in the Bay St. George subbasin.

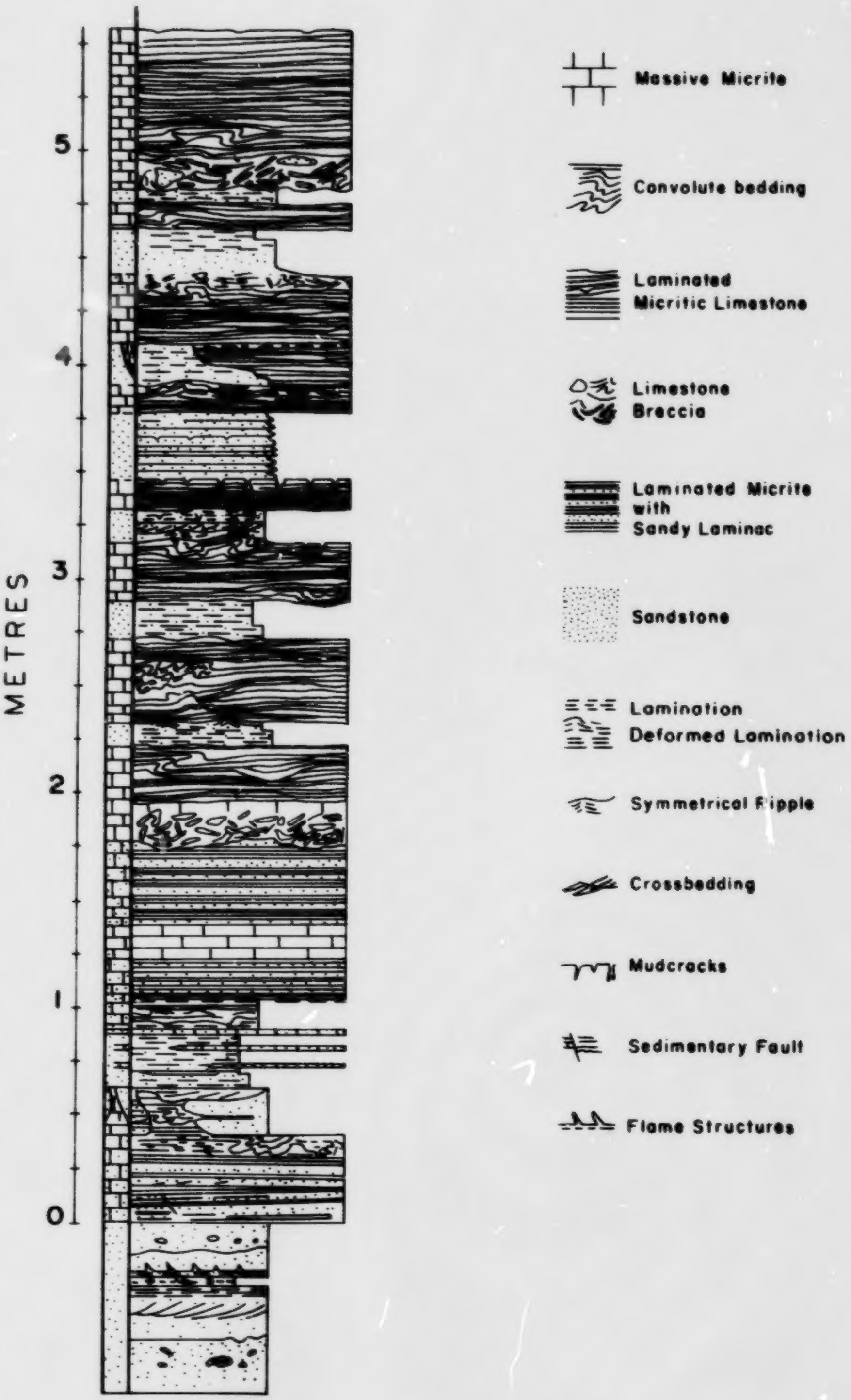

METRES
0
1
2
3
4
5
Massive Micrite
Convolute bedding
Laminated Micritic Limestone
Limestone Breccia
Laminated Micrite with Sandy Laminae
Sandstone
Lamination
Deformed Lamination
Symmetrical Ripple
Crossbedding
Mudcracks
Sedimentary Fault
Flame Structures

Figure 19: Detailed section of the Ship Cove Formation on Codroy Island.

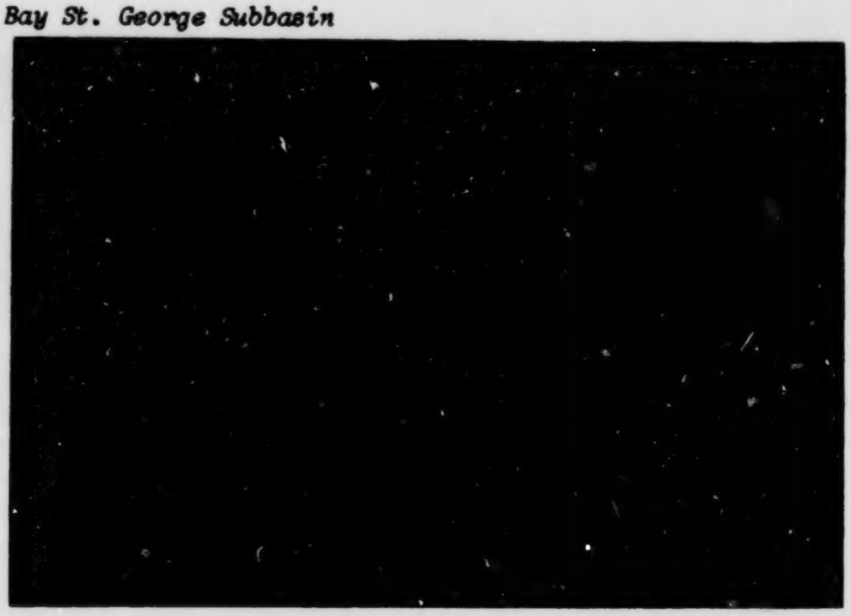


Plate 31: Large, low amplitude ripple-marks formed by segregation of coarse and fine carbonate grains in lithofacies A of the Ship Cove Formation, Ship Cove.

Neomorphism is widespread. Skeletal grains and dark micrite, which originally formed the pellets, peloids and matrix, are replaced by microspar (0.01 mm crystal size) (Plates 33). Recrystallization affects grains selectively in some layers and may obliterate original grain shapes.

Brown to clear, fine, acicular, radiating, isopachous cements coat and line cavities in whole and compacted shell fragments. Radial to blocky clear spar fills the remaining spaces in these skeletal fragments and, in some instances, the spar is in optical continuity with the peripheral, acicular cement. The isopachous layers were fractured prior to the precipitation of the clear spar, supporting an early origin for the drusy layer. Stylolites cut both shells and acicular cements.

Interpretation of lithofacies A: Lithofacies A is comparable to lithosome A of the Macumber Formation in Nova Scotia (Schenk, 1967a and b). It is interpreted as a low energy, shallow subtidal deposit of pellet- and peloid-dominated, lime mud. The facies is similar to that forming in many shallow shelf and lagoonal environments of modern day carbonate production, such as the Persian Gulf (Kendall and Skipwith, 1969; Purser and Evans, 1973), Bahamas (Bathurst, 1975) and Shark Bay, Australia (Hagan and Logan, 1974a and b). This interpretation is supported by the presence of pellet aggregates, oncolites, ooids and skeletal components. Calcispheres resemble those of the Macumber Formation, Nova Scotia (Mamet, 1970) and modern dasycladacean algae that flourish in warm, sheltered, back-lagoon areas of the Florida Keys (Marszalek, 1975).

Many of the pellets in the packstone resemble fecal pellets of modern environments. The sparse fauna suggests, however, that many of the micrite peloids may have been precipitated by algal activity as in hypersaline pools of the Gulf of Aqaba (Friedman et al., 1973) and Laguna Mormona, Baja California (Horodyski et al., 1977). Alternatively, they might have formed by algal degradation of various grains as in Shark Bay, Australia (Read, 1974; Logan, 1974), the Bahamas (Bathurst,

Plate 32: Photomicrograph of oncolitic pellet packstone (lithofacies A) of the Ship Cove Formation from Highlands River. Oncolite has a peloid core.

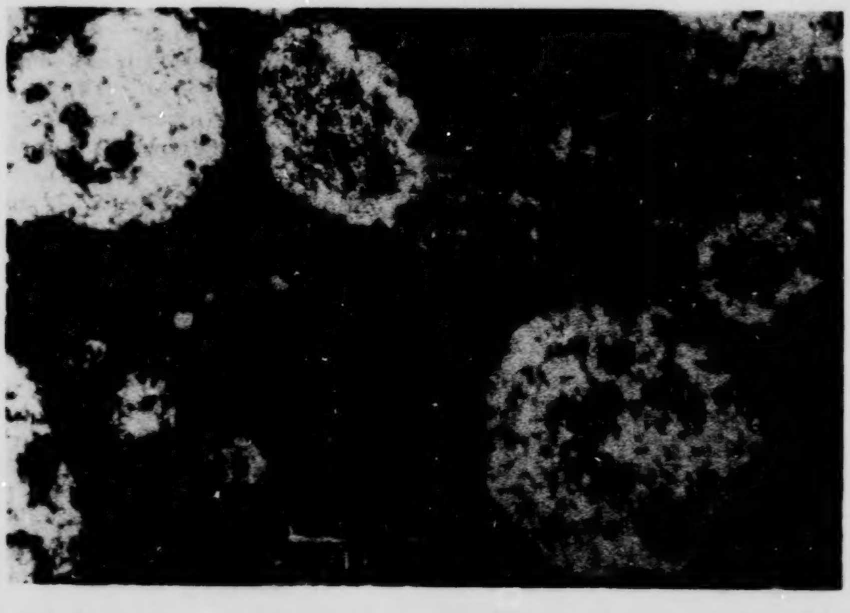


Plate 33: Clear microspar replacing spherical nonskeletal (possibly pellet) grains in wackestone, associated with a small cluster of "coccoid-like" algal spheres, lithofacies A, Ship Cove Formation, Fischells Brook.

Plate 34: Lithofacies B laminites of the Ship Cove Formation at K-295 showing some thin layers of packstone (arrow) and local convolution of lamination.

(1975) and the Persian Gulf (Taylor and Illing, 1969; Kendall and Skipwith, 1969).

Collapse of many shells indicates the packstones have generally undergone some compaction, especially where the mud content was highest. A fibrous, druse cement grew on shells, in some instances before compaction. The presence of acicular radiating cements around skeletal and nonskeletal grains may indicate that early, shallow marine cementation occurred (Taylor and Illing, 1969; Shinn, 1969; Schroeder, 1973; Friedman et al., 1974; Logan et al., 1974; Picha, 1978).

(B) LAMINITE LITHOFACIES

Description of lithofacies B: Lithofacies B consists of gray to blue-black, bituminous, laminated limestone in sequences 2 to 4 m thick. It occurs above basal lithofacies A, and in units 1.5 m thick interlayered with lithofacies C in the middle of the formation. It represents 20% to 50% of the unit as a whole, varying in amount from section to section.

The limestones consist of millimetre-scale, smooth, planar to undulose laminae which generally have good lateral continuity (Plate 34). Micro-discordances are common, however, and erosional surfaces, a few centimetres in relief and imitated by overlying laminae, were noted. Compositional, color and textural variations produce simple alternating or composite-alternating lamination (Monty, 1976) of which three main types are recognized.

Type 1 consists of light and dark laminae composed of microspar or grainy microspar overlain by dark pyritiferous, carbonaceous, silty lime mudstone (Plate 35) or wackestone (Dunham, 1962). Ghost fabrics suggest that pellets, aggregates and intraclasts originally occurred in the light laminae, which now consists mostly of a mosaic of equidimensional microspar, 0.05 to 0.11 mm in grain size. These laminae are locally brecciated and the fractures are sealed by the overlying dark laminae. Rounded to irregular gypsum micronodules, as large as 2 mm in diameter, grew displacively in the laminite at K340 and

Plate 35: Type 1 laminite, lithofacies B of the Ship Cove Formation composed of clear, microspar laminae overlain by dark, carbonaceous, silty laminae. Locality K-375.

probably at K295 (Figure 18). At the latter locality, mosaic spar has filled moldic porosity of similar shape and size to the nodules of K340.

Type 2, referred to here as silty laminite, occurs in couplets 1 to 10 mm thick. It consists of brown microspar laminae which show evidence of having replaced original micrite, coupled sharply or gradationally with laminae of terrigenous silt or very fine sand (Plates 36 and 37). The latter consist of well sorted, angular to subrounded quartz, orthoclase, perthite, plagioclase, green biotite, muscovite, and chlorite. The silt laminae vary from one to several grains thick with little carbonate matrix. Grain orientation, apart from some flat-lying micas or graded layers, is generally absent. Black organic films, ferruginous staining and disseminated pyrite occur towards the top of the silt laminae. Some laminae are composed of 50% microspar enclosing scattered, matrix-supported silt grains. These laminae however, have a swirled, clotted texture that suggests breakdown of the original couplets.

Type 3, called fenestral laminite, consists mostly of silt-free microspar overlain by packstone. In some places the packstone is overlain by porous or nonporous microspar. Type 3 is completed by a carbonaceous micrite cap (Plate 38). The packstones are well to poorly sorted and consist of pellets, peloids, coated grains, oncolites, intraclasts, ooids and skeletal grains. Ooid-rich laminae, now mostly recrystallized, occur near Brooms Brook (K56, Table 5; Plate 39) and at Fischells Brook. Locally spherulites (Friedman et al., 1973), consisting of a micrite or microspar core surrounded by radial, brown colored spar, also occur. Intraclasts are composed of peloid or ooid packstone. Protrusion of grains from the intraclasts may indicate an origin similar to the cemented lumps described from the Qatar Peninsula, Persian Gulf, by Shinn (1969) and Taylor and Illing (1969). Skeletal detritus is similar to that found in lithofacies A. It includes compacted shells in the poorly sorted laminae and uncompacted, complete shells in the well sorted packstone laminae. Brown, fine, acicular cement or clear clusters of radial

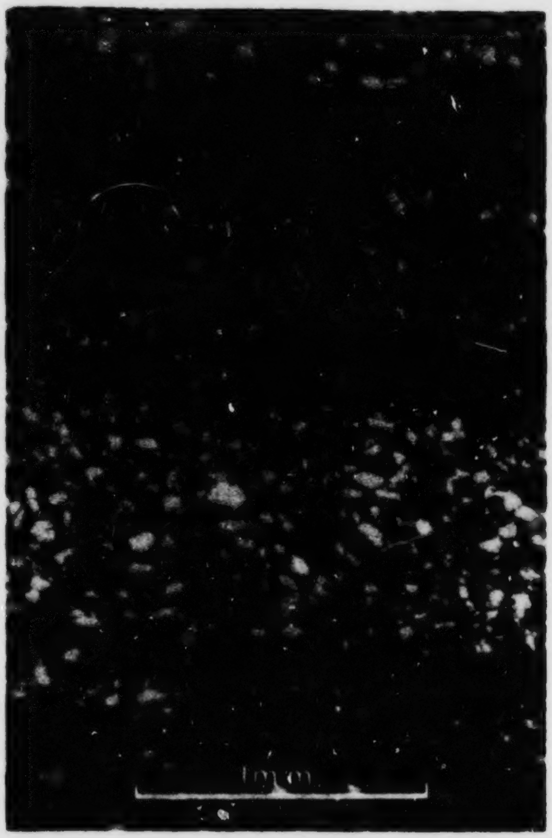


Plate 36: Silty laminite of lithofacies B of the Ship Cove Formation from locality K-56 showing siltstone laminae grading up into silt-free clear to dark microspar or micrite.

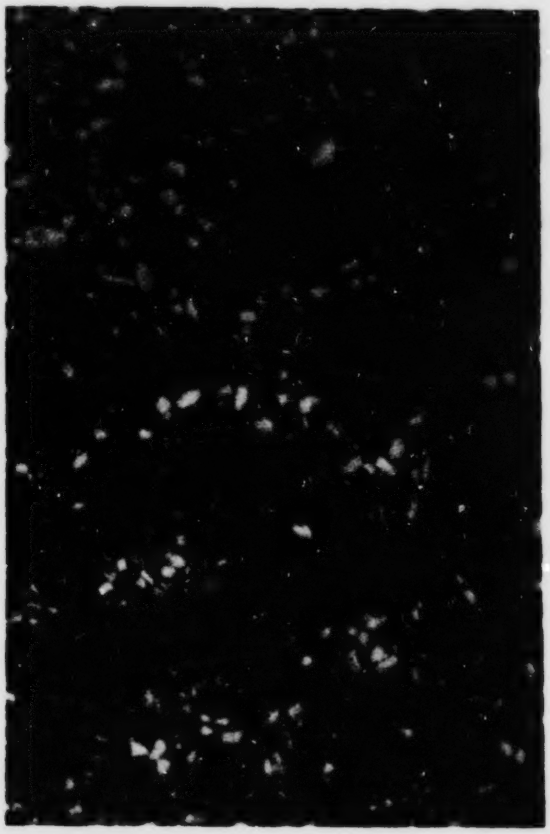


Plate 37: Fracture in silty laminite of lithofacies B, Ship Cove Formation, filled by silt grains from overlying layer. Locality K-56.

acicular needles, speckled by black organic(?) residues, lined shell cavities before compaction. Radial mosaic spar in optical continuity with the fibrous druse fills the remaining intraparticle space much as it did in rocks from lithofacies A.

Organic content, disseminated pyrite and micrite (mostly replaced by 0.02 mm microspar) increases upward to form the top of the type 3 couplets. Laminoid and irregular fenestra (Logan, 1974), which are particularly common from Ship Cove southwestward, occur beneath and arch up the carbonaceous micrite cap. Laminoid pores are up to 3 mm wide and 8 mm long. Clusters of subvertically oriented, skeletal gypsum crystals 1 mm long also underlie the cap in the fenestral laminite on Fischells Brook.

Downward-tapering, silt-filled, microscopic, hairline (Plate 37) to 1/2 cm wide, 2 cm deep fractures cut type 1 and particularly type 2 laminites. Larger fractures also contain brecciated carbonate fragments and were later cemented by spar. The fractures were folded by compaction.

Circular stromatolites, as large as 30 cm in diameter, occur on Codroy Island. They consist of low hemispheroids (Plate 40) displaying a faint concentric pattern of grooves and ridges

Plate 38: Type 3 carbonate-fenestral laminite of lithofacies B, Ship Cove Formation, locality K-56. It is silt-free, with microspar passing upwards to a fenestra-rich layer (f) overlain by a dark, carbonaceous, micrite cap.

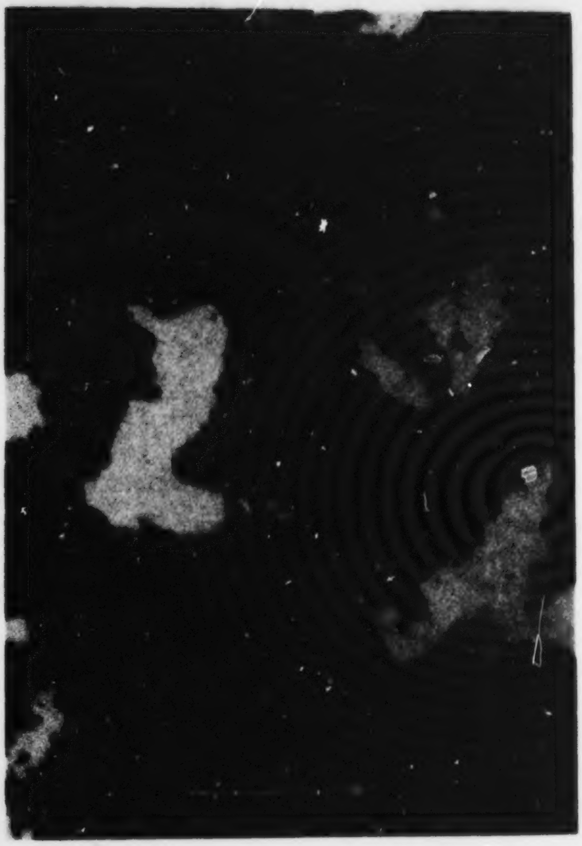


Plate 39: Oolite grains visible in a fenestra-rich laminite that underlies the laminites of Plate 38.

on the top of the mounds. Mudcracks filled by argillaceous carbonate mud cut the top of the hemispheroids.

Small and large scale deformation, mostly in type 2 laminite, occurs in some sections (Figures 18 and 19) but is especially common on Codroy Island. Smaller sedimentary structures include overturned folds, thrust faults and upturned broken laminae. Associated microfabrics in the silty laminites suggest that the microspar laminae, including those enclosing silt laminae one grain thick, were broken up into rigid, platy fragments. Silt from the thicker silt laminae was dispersed to fill interstices produced during the deformation.

Large scale structures (Plates 41) on Codroy Island include box folds, tight chaotic folds, tepee structures and small thrust and reverse faults. The box and chaotic folds are overlain and locally truncated by undeformed bedding.

Interpretation of lithofacies B: The facies B laminites of the Ship Cove Formation are interpreted as deposits of

Plate 40: Spherical algal structures in the Ship Cove Formation, Codroy Island. The stromatolites are flat topped, of low elevation and mudcracked.

Plate 41: Highly deformed laminated limestones of the Ship Cove Formation, Codroy Island.

intertidal to subtidal algal mats which extended over much of the subbasin following deposition of the basal facies A packstones. The abundance of carbonaceous material and the variety of macro- and micro-structures and associated lithofacies (see Table 5) seem to indicate that the laminites accumulated as algal mats in intertidal flats in the southwest; north of Ship Cove they pass into subtidal mats.

Growth and accretion of the algal mats that formed the laminites was encouraged as sediment from two sources moved into the area and was bound within the mat. Pellets, peloids, lime mud and, less importantly, skeletal and other nonskeletal grains were supplied to the flats from offshore lagoons and shoals by tides and storms that flooded the flats.

The second major source of detritus was windblown silt and sand that formed the silty laminites. The composition of the silt and sand, in particular the types of phyllosilicates, points to a provenance southeast of the subbasin. The silty laminites are particularly important in the southwest, where their character supports high intertidal conditions.

In the southwest, intertidal mats are evidenced by: (1) tepee structures (Read, 1974; Park, 1976; Asserretto and Kendall, 1977; Kendall and Skipwith, 1968, 1969) (2) silt-filled fractures; (3) mudcracked, low hemispheroidal stromatolites resembling forms described in shallow pools of the saline flats of Laguna Mormona, Baja California (Horodyski et al., 1977) and (4) fenestral-rich laminite (Shinn, 1968; Logan, 1974; Logan et al., 1974). Tepee structures and related microfabrics (Asserretto and Kendall, 1977) suggest that penecontemporaneous lithification of the algal flats occurred.

Widespread areal development of flat algal mats occurs today where growth is encouraged by low gradient topography, protected conditions, frequent wetting and by hypersalinity (Kendall and Skipwith, 1968, 1969; Kinsman, 1969; Shinn et al., 1969; Bush, 1973; Logan et al., 1974; Kinsman and Park, 1976; Park, 1976). Algal mat preservation is enhanced by: (1) early lithification (Kendall and Skipwith, 1969; Park, 1977), (2) high salinities that inhibit proliferation of browsing organisms (Garrett, 1970; Logan et al., 1974; Gebelein, 1976) and (3) groundwater conditions on the landward side of the tidal flats that are unsuitable for growth of displacive evaporite crystals (Logan, 1974; Logan et al., 1974; Park, 1977). These conditions were apparently met during the deposition of the laminites of the Ship Cove Formation.

The laminites in the north of the Anguille Mountains are typified by their high carbonaceous and pyrite content, dark coloration and abundance of fenestra. The latter possibly formed as gas bubbles trapped beneath decaying mat. The significant carbonate grains in the laminites, together with the gypsum nodules, suggest that the mats formed in the lower intertidal zone. The laminites between Highlands River and Fischells Brook formed in shallow subtidal conditions. This is supported not only by the associated lithofacies but also by nonskeletal grains, the importance of skeletal grains, the associated lithofacies, and the acicular, drusy cements that fill intraparticle porosity in fossils. The cements strongly resemble shallow, subtidal cements forming along the Trucial coast (Taylor and Illing, 1969; Shinn, 1969).

Ooid-rich laminae and some fenestral laminites probably indicate that local oolite shoals provided detritus to the algal flats near Brooms Brook and near the Highlands River and Fischells Brook.

(C) MOLDIC ARGILLACEOUS AND SHALY LAMINITE LITHOFACIES

Description of lithofacies C: Very fine, argillaceous micrites and shaly micrites, in units one to several metres

Plate 42: Very large diameter algal structure on bedding plane in laminite of the Ship Cove Formation, north side of the "round valley", Codroy lowlands. It is overlain by cross-laminated, dolomitic, argillaceous limestone containing moldic porosity after dissolved gypsum crystals.

thick, occupy the upper half of the Ship Cove Formation and comprise approximately 30-50% of the unit as a whole. Lithofacies C is observed to be interlayered with lithofacies B.

The argillaceous micrites are very finely laminated and consist of alternating silt and microspar laminae. They are similar to the silty laminite of lithofacies B but lack organic material. The micrites are rich in moldic porosity that resulted from dissolution of rhomboid crystals that ranged from a few millimetres to 1.5 cm, and rarely several centimetres, in size. Some molds show interpenetrating and swallow-tail crystal shapes. The molds lie at all angles to the lamination they displace and occur with random orientation on bedding planes. Large, flat, circular stromatolite structures, up to 2 m in diameter, are common. The structures consist of a concentric pattern of grooves and ridges (Plate 42).

Mudcracks, silt-filled microfractures, small tepee structures, microscours and cross-lamination, fine breccias, carbonate mudflakes and laminae of nonskeletal packstone are also present.

Interpretation of lithofacies C: The close similarity of lithofacies C to the silty laminite of lithofacies B suggests that it is probably of intertidal to supratidal origin, built up by alternating deposition of carbonate and windblown silt. The ridge and groove pattern of the flat circular stromatolites (Plate 42) resembles that of modern tufted mat (Logan et al., 1974). The latter is known to grow in the middle to upper intertidal zone where drainage is poor or a high water table keeps mat and sediment permanently moist. Evidence of algal mat does not occur in all the finely laminated micrites but microscouring and cross-lamination imply erosion and reworking of the fine sediment, perhaps by wind action. Mudcracks and microfractures, small tepee structures and mudflake

Plate 43: Lithofacies D, limestone-breccia overlying interbedded sandstone and laminite, Ship Cove Formation, Codroy Island. The breccia lies nonerosively upon the sandstone, which is locally buckled. The hummocky top is draped by laminite. Rounded sandstone clasts occur with the platy laminite lithoclasts.

breccias possibly formed by the reworking of dessicated laminite and support a subaerial origin for the facies.

Gypsum crystals that grew displacively in the laminites compare to porphyroblastic gypsum of the upper intertidal and supratidal zone of the Nilemah Flat, Western Australia (Logan, 1974) and gypsum crystals of the supratidal sabkha flats of the Persian Gulf (Shearman, 1966).

(D) INTRAFORMATIONAL LIMESTONE BRECCIA LITHOFACIES

Description of lithofacies D: Lithofacies D is found only on Codroy Island and consists of intraformational, limestone-dominated breccias composed mostly of clasts of lithofacies B laminites, some sandstone, and rare, extrabasinal granite pebbles. The 4-20 cm thick breccias (Plate 43) overlie erosive scours, which transgress underlying laminated sandy limestone or sandstone beds. They are also found above nonerosive bases where they may surround upward-protruding tepee structures. The breccias are overlain by undeformed, laminated limestones which blanket irregularities on the top of the beds.

The clasts are mostly angular plates, 1 to 10 cm in length, of silty laminite or microspar laminae. They are rarely deformed, and lie parallel to and randomly within bedding.

Sandstone clasts are rounded and larger in size. Sand grains are scattered between the clasts, although interparticle and shelter porosity (Choquette and Pray, 1970) is common, except where closed by sparry calcite cement.

Pockets of intraformational breccias also occur in deformed laminated limestones but show no evidence of erosion or transportation.

Interpretation of lithofacies D: Lithofacies D breccias are interpreted to be high energy storm deposits laid down in channels or on hard lithified surfaces of the carbonate flat. A storm origin is evidenced by (1) erosive and nonerosive bases, (2) intraclasts derived from adjacent lithofacies, (3) large quantities of debris, (4) high porosity and (5) rare exotic pebbles. The presence of a lithified carbonate substrate at the time of deposition is suggested by nonerosional contacts and by the preservation of tepee structures. The general lack of sorting or clast orientation indicates rapid deposition. The breccias resemble lithoclastic breccias of tidal creeks in the tidal flats of Sharks Bay, Australia (Read, 1974; Hagan and Logan, 1974b). They compare to breccias described and interpreted as channel deposits by Schenk (1967a and b) in lithosome B of the Macumber Formation of eastern Nova Scotia.

Lithoclasts were possibly derived by erosion of locally brecciated laminite which had previously been deformed and fragmented. This occurred by crystallization pressures as subaerial, vadose cementation and diagenesis affected the tidal flat (Asserretto and Kendall, 1977). Early lithification also probably influenced the nature of the breccias by reducing the amount of fine detritus produced during erosion and facilitated splitting of limestone readily along the lamination to form platy clasts. The granite pebbles probably indicate that the breccias formed close to a pebbly fluvial facies lying landward of the flat.

(E) OOLITIC LIMESTONE LITHOFACIES

Description of lithofacies E: Lithofacies E consists of oolitic-peloid grainstone and oncolitic-oolitic packstones and is uncommon. It is interbedded with oncolitic packstone of facies A in the Fischells Brook section and also occurs at the base of the type section of the Ship Cove Formation.

Oncolitic-oolitic packstones and oolitic grainstones near Fischells Brook are thinly stratified with 4-6 mm wide trails on the bases of beds. The ooids are mostly recrystallized to microspar and display no internal structure. Skeletal fragments and calcispheres are present. Dark carbonaceous laminae, rich in grains and microspar laminae, interrupt the oolitic grainstones.

The basal oolitic peloid grainstone at Ship Cove is structureless. It consists of micritic peloids and ooids. The peloids are surrounded by a thin layer of brown radial calcite and the ooids display a well developed, radial fabric. Partially micritized, skeletal grains, are surrounded by a similar fibrous calcite.

Interpretation of lithofacies E: Although little information is available concerning bed thickness and shape, or internal structure and relationship to adjacent lithofacies, the ooid grainstones seem to be best interpreted as subtidal ooid shoals deposited under conditions of moderate energy and stabilized by growth of algal mat during quiet periods. Calcispheres, skeletal grains and bioturbation suggest that the deposits formed in seawaters which were not highly saline.

The basal peloid grainstone at Ship Cove is, however, quite distinctive, consisting of fibrous, calcite-coated peloids and spherulitic ooids. These allochems bear a striking resemblance to the grains of a marginal hypersaline pool in the modern Gulf of Aqaba (Friedman et al., 1973). Halley (1977) suggested that radial ooids and spherulites are indicative of hypersaline conditions. Similar, radially coated pellets are also described from lithified, shallow subtidal carbonates of Dohat Faishakh, Qatar Peninsula by Taylor and Illing (1969).

(F) SANDSTONE LITHOFACIES

Description of lithofacies F: Two different suites of sandstones are

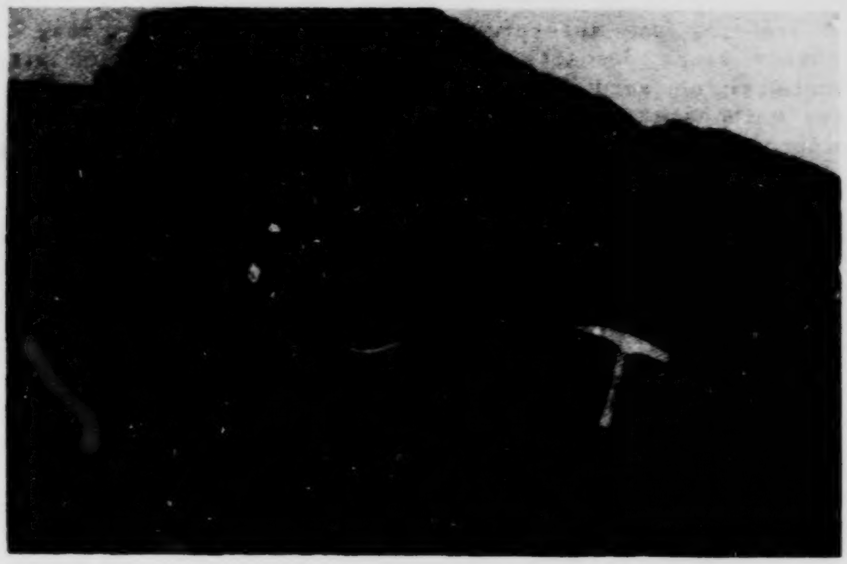


Plate 44: Stratifiedssandstone with some laminite lithoclasts lying in channel eroded in laminite and locally undercutting laminite, Ship Cove Formation, Codroy Island. Bedded sandstone with 1 to 2 cm laminite partings at bottom of plate.

interbedded with limestones of the Ship Cove Formation. The first occurs on Codroy Island in the south (Plate 44) and the second suite in the north in the Fischells Brook sections and on Northern Feeder of Robinsons River.

The sandstones on Codroy Island (Figure 19) are brown weathering, fine to coarse grained, well sorted calcareous arkoses and subarkoses that are similar to those of the underlying Friars Cove Formation. They occur in 10-30 cm thick interbeds or lenses within facies B and D. They overlie sharp, nonerosive or erosive, locally channelled bases. The channelled bases crosscut and undercut laminite beds and tepee structures. Pillars of limestone, which are probably the erosional remnants of once extensive limestone beds, protrude upward in some channels. Limestone and calcareous mudstone intraclasts may occur above the scour surfaces. Nonerosive contacts preserve mudcracks and drape over highs in underlying limestone beds.

The sandstones are usually planar stratified or laminated but locally display ripple cross-lamination which gives a westward paleoflow direction. In one channel sandstone, intraclastic sandstone grades up into massive sandstones capped by lamination. Mudcracked shale partings and interlayered sandstone and laminated limestone are also present.

In marked contrast, the sandstones of the Fischells Brook area (Figure 18) consist of green-gray, argillaceous and micaceous, poorly sorted siltstones to fine sandstones interbedded with gray shales and thin limestone beds. The sandstones vary in thickness from 5 to 45 cm and are internally laminated and cross-laminated. Bases carry flute casts, brush marks and load casts, whilst tops are ripple-marked, coated in plant debris and mica, or show parting lineations. Petrographically, they are composed predominantly of angular, in cases splintery, quartz set in coarse calcite cement with patchy clay matrix.

Chlorite, muscovite and minor biotite are the dominant phyllosilicates; plagioclase, scattered zircon, green tourmaline, rare garnet, magnetite, sphene and leuxocene complete the detrital suite. Amorphous red to brown oxides coat some of the grains.

Interpretation of lithofacies F: Lithofacies F sandstones from the southwest and north of the subbasin contrast strongly with each other. On Codroy Island, planar stratified, well sorted sandstones are interbedded with lithofacies B laminites. They were deposited either in channels eroded in the carbonate flats or when floodwater overflowed such channels and deposited sand as a sheet upon the carbonate flat. Westward paleoflow and arkosic composition suggest an easterly derivation for the sandstones.

The poorly sorted, argillaceous and micaceous sandstones of the Flat Bay area were deposited subaqueously with shales. Fluted bases, internal structure and soft-sediment deformation suggest that the sands were deposited by low density underflows discharged from a river mouth (Hsu and Kelts, 1978) into the shallow marine environment.

(G) OTHER ROCK TYPES

Description of lithofacies G: In some sections in the Anguille Mountains, some thin beds or partings of green and gray shale or red mudstone interrupt facies B and C laminites. The gray shales are smooth and structureless. Red mudstone is associated with a gray, fine sandstone in the middle of the section at the head of Brooms Brook (K225, Figure 18). The thickest deposits of gray shale occur in the Fischells Brook area where they are interbedded with thin sandstones and limestone beds. Bioturbation, oncolites, oolites, skeletal remains as well as some lime beds with mudchip pavements and small mudcracked surfaces are associated with the Fischells Brook shale sequence.

Interpretation of lithofacies G: Gray shales probably accumulated on the intertidal algal flats where they may have been trapped on the wet mat or have accumulated in shallow pools locally developed on the flats in the southwest. Much of this fine detritus was probably deposited subaqueously as windblown fines. Red mudstone and gray sandstone in the same area (K225) suggest terrigenous deposits prograded locally over the carbonate flat.

The gray shales that are interlayered with sandstones and thin limestones in the Fischells Brook area accumulated in quiet water from the turbid, muddy discharge of a river. Structures in associated beds suggest the water was generally only a few metres deep and, in some instances, deposits were subaerially exposed.

Paleontology, age and correlative deposits of the Ship Cove Formation

Smooth-shelled brachiopods (*Composita* sp?, Moore and Ryan, 1976), ostracod fragments and well preserved conodonts are found in the Ship Cove Formation. An abundant conodont fauna occurs in the basal centimetres of the formation, but is limited to *Cavusgnathus windsorensis* and one or more species of *Diplognathodus* (von Bitter, 1975; von Bitter and Plint-Geberl, 1978, 1979, 1982). The conodonts are assigned to the *Diplognathodus* zone by von Bitter and Plint-Geberl (1982) and the formation to Windsor subzone A (von Bitter, 1975; von Bitter and Plint-Geberl, 1979, 1982). It is strikingly similar, lithologically, to the basal Macumber Formation of the Windsor Group in Nova Scotia with which it is correlated (see Table 10).

Depositional environment of the Ship Cove Formation

Two models of deposition have been proposed for correlative limestones of the Windsor Group of Nova Scotia. The first model interprets these limestones as the deposits of a prograding, tidal flat similar to the modern day Trucial Coast (Schenk, 1967a and b). The second and later model proposed by Geldsetzer (1977, 1978) and Kirkham (1978) interprets limestones of the Macumber and Ship Cove Formations to have been deposited in quiet, relatively deep water (20-50 m) following marine flooding of the early Carboniferous inland molasse basin.

The distribution and characteristics of the lithofacies (see Table 5) in the Ship Cove Formation of the Bay St. George subbasin suggest that the formation was deposited dominantly in a tidal flat complex. During deposition, the subbasin was confined by mountains, southeast of the Long Range fault, and by the Port au Port ridge to the north. Subtidal conditions were maintained in the northern part of the subbasin, whilst tidal carbonate flats occurred in the area of the Anguille Mountains. In the north the proposal of a dominantly shallow subtidal environment is supported by the fauna, the extent of bioturbation, the importance of oncolites, pellets and ooids, and the association of limestones with shales and thin turbidite-like sandstones. In the area of the Anguille Mountains a tidal flat complex is evidenced by tepee structures, mudcracks, and channel-bound limestone-breccias and sandstones. Further indications are the paucity of skeletal remains in the laminites and the importance of silty and fenestral laminite with some gypsum nodules and stromatolite structures.

Subtidal pelletal packstone and wackestone (lithofacies A) were deposited over much of the area following marine flooding of the subbasin. In the Flat Bay area, however, more than 15 m of shales and interbedded, fossiliferous, oncolitic packstones and thin 'turbidite-like' sandstones are seen below the more typical Ship Cove limestones. They suggest that flooding began earlier and was maintained longer in the north of the subbasin.

Pelletal packstone was not deposited in the Codroy area and here the basal beds of the Ship Cove Formation consist of silty and fenestral laminites. Channel-bound sandstones and limestone-breccias within these laminites resemble channel deposits of the intertidal flats of Shark Bay, Australia (Read, 1974; Hagan and Logan, 1974b). Tepee structures indicative of early, subaerial lithification (Asserretto and Kendall, 1977) and low hemispheroidal stromatolites similar to forms found in shallow pools of modern saline flats (Horodyski et al., 1977) together suggest that the landward edge of the tidal flat lay in the Codroy area. Mudcracked horizons are also common. This lateral facies variation at the base of the formation strongly implies a gradual transgression from northwest to southeast rather than a sudden flooding as suggested for the Maritime Basin by Geldsetzer (1977, 1978). It is similar to facies changes described for the recent transgressive history of the basal carbonates of the Trucial Coast (Evans et al., 1969).

As sea level stabilized, the intertidal flat broadened to prograde northward over the basal packstones. The landward edge of the tidal flat was maintained in the southwest. Here it was periodically blanketed by sheetwash sand deposits that were derived by reworking of sand from an exposed alluvial fan, fluvial system or perhaps aeolian deposits that lay along the foot of the paleo-Long Range highlands. In the lower part of the intertidal zone, flat algal mats flourished over a very extensive, low-lying, sheltered area that occurred in the central part of the Anguille Mountains. The mats were built up of carbonate detritus washed from offshore (type 1 and 3 laminites) or by windblown sand and silt derived from the landward side of the tidal flat. Decomposition of the mat produced fenestra and disseminated iron sulphides.

Nodular and skeletal gypsum formed in the lithofacies B laminites of the lower intertidal zone. Porphyroblastic gypsum crystals in moldic laminites developed higher in the intertidal zone as salinity of groundwaters increased. However, no advanced nodular gypsum or anhydrite growth occurred, which implies that the tendency for continued concentration of brines in the landward portion of the mats was somehow offset (Bush, 1973; Read, 1974). This was perhaps affected by a number of factors and could have included the presence of fresh meteoric groundwater and high siliciclastic content. In addition, early lithification and impermeability of algal mat layers might have impeded landward movement of marine waters (Bush, 1973). A high water table that kept the surface mat damp may have helped prevent the formation of dessication cracks. Circular stromatolites of the moldic laminite facies resemble tufted mat that grows in areas of poor drainage and/or a high water table on modern intertidal flats (Logan et al., 1974).

The composition of the silt and sand indicates that its provenance was in the area of the Long Range Mountains. This suggests that it was carried onto the tidal flats by a prevailing east or southeast wind that deflated alluvial sediments along the inland edge of the flats. The sediment was probably blown as a thin sheet over the flats (Allen, 1970b; Glennie, 1970). It was trapped on the sticky algal mat, particularly at low tide (Park, 1976), or accumulated in shallow pools on the flats. Park (1976) believes most windblown terrigenous sediment accumulates in the intertidal zone of the Trucial coast and does not reach the offshore. Lack of grading or mineral segregation in the silty laminae is consistent with this hypothesis.

Shallow marine conditions were maintained for much of the history of the Ship Cove Formation in the northern part of the subbasin where a sparse fauna was active. Oncolitic oolite shoals were locally developed. Algae played an important role in binding sediment and micritizing and pelletizing the skeletal and nonskeletal carbonate grains. Submarine lithification is supported by (1) reworking of lithified pellet and ooid packstone, (2) alternation of layers of whole and collapsed shells, and (3) intraskeletal, acicular cements. Similar lithification processes are known in aproximately 2 m deep tropical seas (Taylor and Illing, 1969; Shinn, 1969; Picha, 1978). Muddy and very fine, sandy, terrigenous detritus was supplied by rivers discharging into the northeast part of the marine basin.

The basin probably became more restricted as sedimentation continued. Evidence of nodular gypsum replacing the top of the Ship Cove limestone at Romaines Brook implies the establishment of a southward prograding tidal flat and sabkha attached to the Port au Port ridge in the north. Similar nodular gypsum at Flat Bay probably implies that the prograding sabkha was extensive or that a separate evaporitic tidal flat was established about an arch cored by Precambrian basement rocks.

Red beds and gray beds and gypsum overlie the Ship Cove Formation in the areas south and north of the Anguille Mountains respectively. This facies arrangement suggests nonmarine beds prograded northward across the subbasin so that the history of the Ship Cove Formation ended when the fine alluvium of the Codroy Road Formation blanketed the deposits of the inland sea.

Codroy Road Formation

Definition and distribution

The Codroy Road Formation is the name proposed for a mixed sequence of fine siliciclastic, carbonate and evaporitic sedimentary rocks that was previously called the Codroy Shales (Hayes and Johnson, 1938) and was included in the lower Codroy Group by Baird and Cote (1964). It is not easily defined because the character of the formation is variable from north to south and the generally incompetent strata have suffered strong deformation in the area peripheral to the Anguille Mountains.

The formation is named after the navigation channel that leaves the small harbour of Codroy. In the Codroy area, the formation is exposed in cliffs from Codroy Village south to a major fault just south of Black Point. This fault separates the Codroy Road Formation from the younger Woody Cape Formation. The former formation is also extensively developed along the northeast side of the Codroy lowlands and in the "round valley". A well exposed coastal section occurs north of the Anguille Mountains near Ship Cove, from where the rocks can be mapped inland to the Highlands River. Both the Codroy and Ship Cove sections are complicated by folding and faulting. The formation is also mapped around the Flat Bay anticline and occurs near Romaines Brook, west of Stephenville. In the north the best exposed, although incomplete, section lies along Fischells Brook east of the Canadian National railway bridge. Quarry workings at the Flintkote gypsum mine at Flat Bay also provide good exposure.

The base of the formation is conformable or gradational upon the shaly carbonates of the underlying Ship Cove Formation. In places it is sited where displacive gypsum has replaced the top of the Ship Cove limestones (see discussion of upper contact of the Ship Cove Formation for descriptions).

The upper contact is not easily defined except at the Fischells Brook section where it is placed at the top of the uppermost gypsum deposit (Figure 20 on foldout C; unit 8 of section L, Bell, 1948) that crosses the brook near the railway bridge. The upper contact is placed at the top of the Black Point limestone at Codroy and above the gypsum unit that directly overlies the Cormorant limestone at Ship Cove. These two limestone markers are correlated because they are both overlain by fine redbeds with limestone-breccias (Codroy Breccias, Bell, 1948) of the Robinsons River Formation. Lack of carbonate at the top of the section on Fischells Brook makes definite correlation of the top contact from area to area impossible. It is felt, however, that the contact defined here represents a distinct sedimentation break in all areas and, furthermore, it quite possibly reflects a common geologic event.

Thickness

The thickness of the Codroy Road Formation is not easily calculated because most sections through it are structurally complicated. Approximately 145 m was logged in the section along Fischell Brook (Figure 20), although Bell (1948, units 3 to 6, section L, page 33) calculated it to be 244 m thick. The section at Ship Cove is estimated to have a thickness of approximately 120 m. In the Codroy Valley, the formation may be 300 m thick but the section is badly transected by faults.

General lithology

The Codroy Road Formation has a variable lithological character but always includes fine grained siliciclastic rocks, evaporites and minor carbonates. The fine siliciclastics are represented by red siltstones and fine sandstones and a variety of drab colored rock types. The latter comprise multicolored laminated siltstones, gray evaporitic shales, and gray to blue-black mudstones and siltstones. The evaporites consist of varicolored gypsum and blue-gray anhydrite. Carbonates include mostly dark gray to black, bituminous dolomites and fossiliferous, dolomitic, mudstones and muddy dolomites; shelly, biohermal limestones or dolomites are also locally present.

Red and gray siliciclastics with interbedded evaporites and minor carbonates comprise the Codroy Road Formation around the Anguille Mountains. Redbeds gradually give way northward of Ship Cove to gray beds and evaporites; north of Robinsons River evaporites become the dominant rock type.

These lithologies arranged in repetitive sequences occur in the Codroy and Ship Cove sections and were logged in drill core near Ryans Brook, Codroy lowlands (McKillop, 1953b). Similar sequences are absent, however, in sections further north and in drill logs at Highlands River (McKillop, 1953a; Smith, 1953). There, most successions consist of a gray facies interbedded with, or overlain by, gypsum and capped by redbeds. Other sequcnces are made up of gray beds with minor gypsum capped by 10-20 cm thick redbeds, themselves locally containing gypsum nodules. Where carbonates occur in the Codroy Road sequences they overlie gray and black siliciclastics and pass up into gypsum with or without redbeds. At Ship Cove, two megasequences occur; gray beds are generally dominant low in the megasequences but pass upward into the redbeds.

Six lithofacies are defined in the Codroy Road Formation. They are: (A) red siltstone and sandstone lithofacies, (B) multicolored laminated siltstone lithofacies, (C) gray evaporitic shale lithofacies, (D) gray and blue-black mudstone and siltstone lithofacies, (E) evaporite lithofacies and (F) carbonate lithofacies.

(A) RED SILTSTONE AND SANDSTONE LITHOFACIES

Description of lithofacies A: Fine redbeds composed either of structureless siltstone or of thin sandstones interbedded with siltstones form units up to 15 m thick in both the Codroy and Ship Cove sections. Thick, structureless siltstones generally weather with a hackly fracture and contain horizons with cubic crystal molds a few millimetres to 1 cm in size. Cross-laminated siltstones from 4 to 20 cm thick lie gradationally within some units.

Green to red, very fine sandstones are as thick as 40 cm. They overlie sharp bases and consist of planar lamination passing up into ripple-drift cross-lamination. Parting lineation is exhibited on planar lamination. Small channel scours filled with crossbeds erode into the top of some sandstones; rootlet impressions and mudcracks penetrate the top of others. The sandstones grade up into structureless, green-mottled, red siltstones that may enclose carbonate concretions.

Interpretation of lithofacies A: The red colored, fine grained nature of these sediments, indicates that they are probably alluvial plain deposits. The current-bedded sandstones were likely deposited by shallow intermittent streams with sheetfloods or perhaps wind reworking the fine alluvium. Mudcracks, limited distribution of plant rootlets, presence of caliche nodules (Gile et al., 1966; Leeder, 1975) and horizons of salt molds all indicate that the climate was at least semiarid. The salt crystals probably formed within the alluvium close to or on a playa flat by precipitation from groundwater brine (Smith, D.B., 1971; Kendall, 1979a).

(B) MULTICOLORED LAMINATED SILTSTONE LITHOFACIES

Description of lithofacies B: Multicolored siltstones consisting of gray, red, purple, black, cream and green laminae form units up to a few metres thick in the Ship Cove and Codroy sections. They are associated with other gray siliciclastic rocks. The siltstones are finely laminated on a millimetre scale and consist of rhythmic alternations of muddy, medium to coarse siltstones grading up into silty mudstones. Some thicker, very fine sandstone laminae may also occur. On a large scale, the laminations appear planar and regular, but polished surfaces reveal small scale crenulation, disruption, rupture and irregular thickness of the laminae. Soft-sediment deformation such as convolution and faulting affect 0.5 to 1 cm layers and millimetre-scale load casting also occurs, giving the lamination a ptygmatic, bulbous appearance. Cubic pyrite crystals and cubic halite molds speckle the lamination.

Silt and sand laminae consist of angular quartz grains together with muscovite, green and brown biotite and chlorite. Authigenic rhombic dolomite is scattered in some laminae.

Interpretation of lithofacies B: The graded, delicate lamination and widespread halite pseudomorphs and molds suggest that lithofacies B was laid down subaqueously in quiet, hypersaline water bodies. The graded laminae reflect the periodic influx of sediment into the water body with density and size settling producing the grading. Microscopic and small scale deformation formed in response to compaction and loading.

(C) GRAY EVAPORITIC SHALE LITHOFACIES

Description of lithofacies C: Lithofacies C is particularly important from Ship Cove to Robinsons River but it also contributes to the section at Codroy. Evaporitic shales are also known from drill core in the Highlands River and the Fischells Brook areas where they occur between sulfate evaporites. In the Ship Cove area, 10 to 15 m of gray shale and some red, gypsiferous shale form the basal unit above the Ship Cove limestones. Lenses of selenite and beds of argillaceous, sugary gypsum are intercalated with the shales. Traced northward, the facies becomes sandier.

Interpretation of lithofacies C: The gypsiferous shales were deposited as argillaceous particles that continuously settled to the bottom of a quiet, muddy, hypersaline water body. Lensoid deposits of selenite crystals may indicate that rafts of gypsum formed on the bottom as the water body became supersaturated with $CaSO_4$. They may have formed in a similar fashion to those described from the marginal saline pools of the Gulf of Aqaba (Eckstein, 1970). Beds of argillaceous, sugary gypsum were deposited when supersaturation lasted for prolonged intervals. The waters were probably aerobic as pyrite is absent.

(D) GRAY AND BLUE-BLACK MUDSTONE AND SILTSTONE LITHOFACIES

Description of lithofacies D: Sediments of lithofacies D occur in units 40 cm to 17 m thick in the Codroy and Ship Cove section where they are associated with facies B and interlayered with facies A. They are composed mostly or completely of pale gray siltstone and mudstones or less commonly of blue-black to black mudstones interbedded with gray sediment. The gray siltstones form sheets 2 to 15 cm thick within the mudstones and there they are massive, thinly stratified, laminated or cross-laminated. The gray siltstones are generally graded, passing up into structureless or laminated gray mudstones. Molds after cubic halite, 2 to 5 mm in size, are common in both rock types. Interrupting the gray sediments are structureless or laminated, blue-black or black, waxy mudstones. These rocks are rich in fine pyrite cubes and form layers as thick as 1 m.

Interpretation of lithofacies D: The abundant halite molds in lithofacies D suggests that it was deposited in a hypersaline, subaqueous environment like lithofacies B with which it is intercalated. Relatively thick, graded, laminated and current bedded siltstones probably indicate that facies D was deposited close to the margins of a water body by decelerating bottom currents. Fines settled out from suspension when currents waned, so that the siltstones give way upward to mudstones. When stagnant, anaerobic conditions prevailed in the water body, the black, pyritiferous mudstones were laid down.

(E) EVAPORITE LITHOFACIES

Description of lithofacies E: The gypsum and anhydrite in the Codroy Road Formation occur throughout the subbasin. Gypsum is mostly found in surface exposures but passes underground into anhydrite (Baird, 1951; McKillop, 1959). Previously, four gypsum zones had been delineated in the Codroy Group by Bell (1948) and Baird (1951). The formation as defined now includes the two lower zones A and B, which should not be confused with the biostratigraphic subzones of the Windsor Group.

Zone A evaporites are 60 to 150 m thick. They occur immediately above the Ship Cove Formation in the north of the area at Romaines Brook (McKillop, 1955, 1959), around the northern end of the Flat Bay anticline (Baird, 1949, 1951; McKillop, 1959) and at Sheep Brook and Coal Brook (Baird, 1949, 1951). The evaporites of zone A appear to thin southward from the Flat Bay area, becoming interbedded with gray shales and siltstones near Robinsons River, Ship Cove, and in the Highland River area near Bald Mountain (McKillop, 1953a; Smith, 1953). The evaporite zone appears to be poorly developed in the Codroy lowlands where fine red and gray beds are intercalated with impure, 1 to 5 m thick gypsum beds (McKillop, 1953b).

Zone B evaporites occur higher in the Codroy Road Formation. They are commonly associated with gray shales and siltstones, red siltstones and black carbonates. This second evaporite lithofacies is found with the Black Point and Cormorant limestones and a series of carbonates in the "round valley" area. At least three gypsum beds are present in the Codroy area below the Black Point limestones and three are also associated with dark limestones in the Highlands River area (McKillop, 1953a; Smith, 1953). At Ship Cove, gypsum of zone B overlies the Cormorant limestone. The upper gypsum unit in the Fischells Brook section (interval 8, Section L, Bell 1948, p. 33) may be equivalent to zone B gypsum but there is no obvious break in the succession to separate Zone A from Zone B gypsum (Figure 20).

In the northern part of the subbasin, the evaporites consist of (1) white, gray, black, red and yellow (Baird, 1951), fine and powdery to massive and sugary, crystalline gypsum, (2) coarse to needle-like selenitic and fibrous gypsum and (3) blue-gray, massive, crystalline anhydrite. Fibrous gypsum veins commonly cut associated strata some distance away from the main evaporite bodies. Thin interbeds, laminae and partings of gray shale, limestone, buff crystalline bituminous dolomite and shaly dolomite occur within the evaporites. Clear halite forms streaks locally in the gypsum at Flat Bay.

The deposits at Flat Bay, Fischells Brook and Romaines Brook are well bedded (Plate 45) with local discontinuity surfaces separating sequences with slightly differing bedding attitudes. Massive, contorted, and ropy bedding (Plate 46), and mosaic, distorted mosaic, bedded mosaic and nodular mosaic structure (Plate 47) (Maiklem et al., 1969) are observed in the gypsum. Mosaic structure is most common and forms beds 2 - 6 cm thick separated by 2 mm to 2 cm laminae of carbonate or shale. Enclosed within the nodular structure of the mosaics are remnants of carbonate or shale laminae. These thinly stratified and laminated carbonates make up beds as

Plate 45: Bedded gypsum of the Codroy Road Formation, Flat Bay gypsum mine, showing dark dolomitic laminae between white gypsum layers that are composed of coalesced nodules.

Plate 46: Thick layer of Ship Cove Formation type laminite set between two thick beds of white gypsum, Codroy Road Formation, Fischells Brook. Nodular gypsum clearly grew displacively in the laminite.

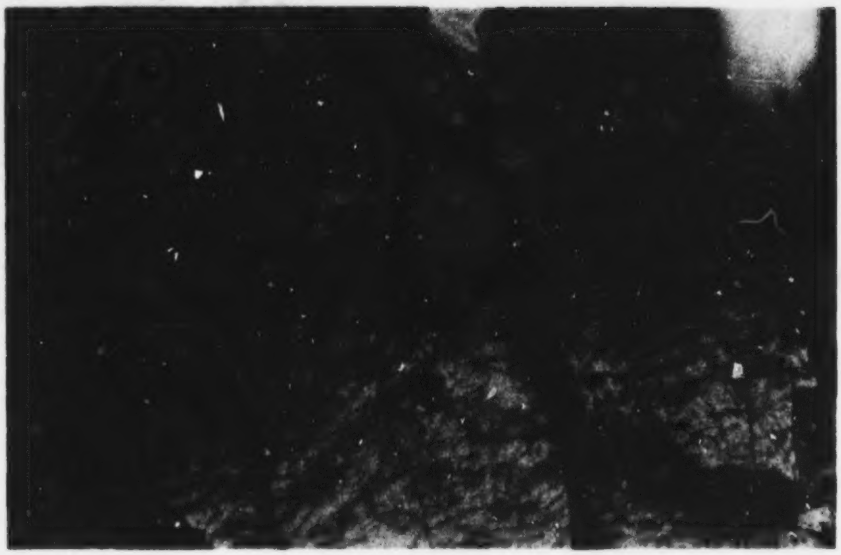


Plate 47: Nodular to contorted bedded gypsum with dolomite streaks interbedded with thin bedded, deformed argillaceous dolomite containing folded and overthrust bedding and small, fluffy gypsum nodules. Codroy Road Formation, Flat Bay gypsum mine. Lens cap for scale, 6 cm wide.

thick as 40 cm. The laminations are buckled, folded and thrust faulted by synsedimentary deformation (Plate 47). Beds lack lateral continuity because of the destructive growth of the nodular gypsum.

White colored, gypsum laminites (Plates 48 and 49) occur near the base of the Fischells Brook section and are composed of planar laminae of gypsum and dolomite. Gypsum laminae consist of a felted mat of gypsum needles, while dolomite laminae contain scattered silt detritus. They include structures reminiscent of LLH stromatolites (Logan et al., 1964) (Plate 48) and the stromatolitic gypsum of the Solfifera Series of Sicily (Hardie and Eugster, 1971). Displacive nodular gypsum and enterolithic folds are also common (Plate 49) (Shearman and Fuller, 1969).

Grass-like, coarsely crystalline selenite (Schreiber et al., 1976) is noted in one of two gypsum beds that overlie the Cormorant limestone. These beds are separated by gray shales. The selenite occurs in layers a few centimetres thick. It is composed of elongate, rhomboid, gypsum crystals that appear to have been nucleated upon the surface of the underlying shale and grew perpendicular to the basal bedding plane. The lower bed displays distorted mosaic structure (Maiklem et al., 1969) and sits above the limestone.

The gypsum deposits in the vicinity of the Anguille Mountains are generally severely affected by the deformation of the host rocks. The deposits in the Codroy area, for example, appear to be vertical dikes, sheets and plugs. Despite their crosscutting relation with bedding, some are still essentially in their original stratigraphic position. In the mobilized deposits, however, gypsum is characterized by a light and dark banding produced by needle-like selenite crystals 0.5 to 1 cm long, aligned parallel to banding. Flow folds and pinch and swell structures are common; fragments of black, argillaceous, bituminous, locally fossiliferous dolomite, some 1 m in size, are irregularly distributed in the banding. Veins and large areas of coarse crystalline selenite also occur. Locally, the gypsum displays mosaic and

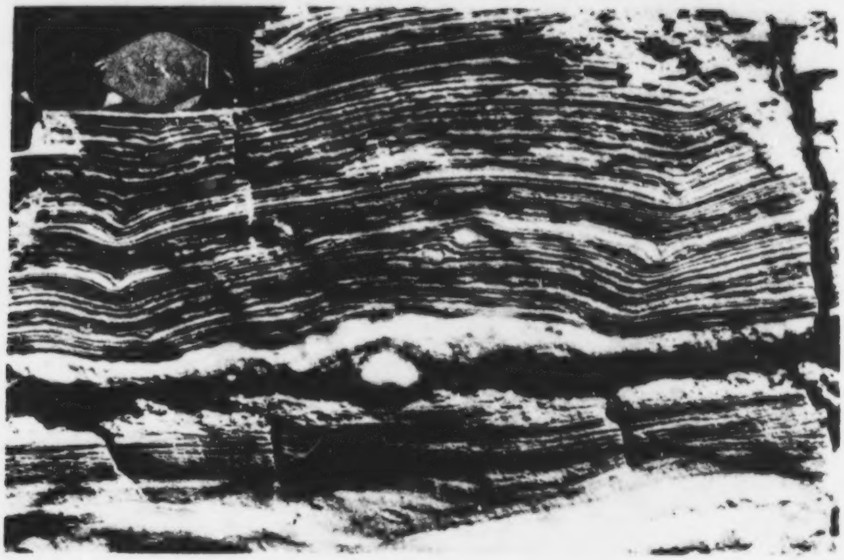


Plate 48: Gypsum laminites of the Codroy Road Formation with local structure resembling flat algal mat and containing small, displacive gypsum nodules, Fischells Brook.

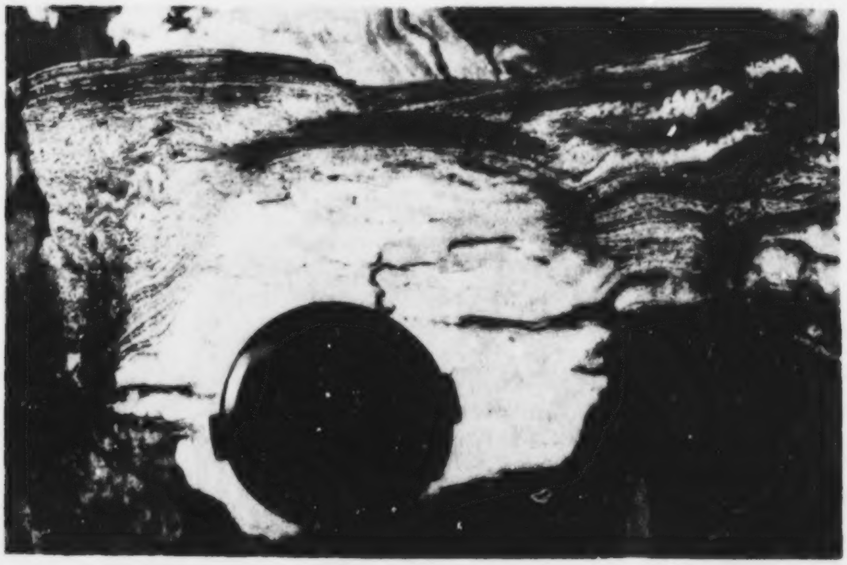


Plate 49: Large, white gypsum nodule and local layers of enterolithically folded laminae in gypsum laminite of the Codroy Road Formation, Fischells Bay.

bedded structure. Ribbon-like banding of gypsum and gray shales is recorded in a drill log from near Ryan's Brook (McKillop, 1953b). The descriptions also suggest nodular gypsum displacing red siltstone as well as the interlayering of the gypsum and the gray beds.

Interpretation of lithofacies E: The well bedded, predominantly nodular gypsum found in the north of the subbasin displays only minor discontinuity and no evidence of large scale erosion, channelling or slumping. This suggests the evaporites formed within a relatively stable, sabkha environment. Here they grew displacively within gray shales and laminated carbonates which also preserve tepee structures. Such structures may indicate an origin on intertidal or supratidal, carbonate-evaporite flats (Shearman, 1966; Kendall and Skipwith, 1969; Evans et al., 1969; Asserretto and Kendall, 1977). Replacement of the limestones at the top of the underlying Ship Cove Formation at both Romaines Brook and Flat Bay (McKillop, 1959) strengthens this conclusion.

Other types of gypsum are not common but the laminar gypsum of Fischells Brook is noteworthy. Such laminar gypsum may form by rhythmic precipitation of evaporite and carbonate within a standing body of water (Murray, 1964; Kendall, 1979 a & b). This kind of structure may also form by mechanical deposition of gypsum swept from a subaqueous environment onto intertidal algal mat (Hardie and Eugster, 1971) or by coalescing of small displacive nodules within algal mat carbonates (Shearman and Fuller 1969). LLH stromatolitic structure supports the contention that they are intertidal deposits. The presence of small displacive nodules and enterolithic structure also suggests the laminite formed as intertidal mat and was later affected by displacive gypsum growth.

The grass-like selenite of the upper gypsum bed above the Cormorant limestone is similar to selenite-layered structures of Messianian evaporites of Sicily (Hardie and Eugster, 1971; Schreiber at al., 1976). It is also comparable to gypsum crystals in shallow, man-made, brine pools (Schreiber and Kinsman, 1975) and in the shallow waters of Marion Lake, South Australia (Hardie and Eugster, 1971). The selenitic gypsum overlies a lower bed of nodular gypsum of probable sabhka origin, suggesting deposition of the gypsum of the two beds occurred mostly in shallow water pools or lagoons and in the intertidal zone.

Deformation of the deposits in the south of the subbasin destroyed original features so that environmental comparison with the northern deposits is difficult. Of interest, however, is the presence of the fragmented black dolomites in the gypsum, the association of gypsum beds with the black dolomites or biohermal buildup, and the position of the gypsum between gray siliciclastics below and redbeds above. Where gypsum caps biohermal limestones there is good evidence for the subaqueous precipitation of gypsum. Freshwater vadose diagenesis did not alter the "round valley" reef, for example, before the overlying gypsum was laid down. Where the evaporites form in the gray to red siliciclastic cycles, deposition was probably in shallow restricted or land-locked lagoons. The cyclic sequences seem to imply a number of transgressive-regressive events involving flooding and dessication. In the less deformed units in the southern part of the subbasin, coarse selenitic gypsum is common and these occurrences may also argue for subaqueous deposition (Kendall, 1979b) in lagoons or land-locked depositories.

(F) CARBONATE LITHOFACIES

Description of lithofacies F: The carbonates of the Codroy Road Formation are black and buff colored dolomites which are silty and argillaceous. Many lithofacies F carbonates grade into dolomitic or calcareous, silty mudstones. Limestones do occur but they are subordinate. The best known units are the Black Point limestone of the Codroy area and the Cormorant limestone of Ship Cove (Bell, 1948). Other carbonates are observable at Codroy, along the North Branch River near "round valley", on a southern tributary of the North Branch River near the Long Range fault and on Highlands River near Bald Mountain (McKillop 1953a; Smith, 1953). Some of the lower carbonates on the Barachois River may also belong to this same depositional period.

The uppermost carbonates, the Black Point and Cormorant limestones, although probably deposited at about the same time, clearly have stratigraphic relationships which suggest they are not one bed. They both vary rapidly in thickness from section to section and the Black Point limestone is transgressive when traced from north to south in the faulted coastal section. In the north, the 'limestone' occurs 46 m above a gypsum bed but comes to sit almost directly on the evaporite to the south as intervening redbeds pinch out. At Ship Cove, the Cormorant limestone thins rapidly southward to form a minor limestone bed beneath decimetre-thick gypsum deposits which also cap the thickest part of the bioherm. In the Codroy area brecciated fragments of black carbonate within gypsum indicate that other beds, now destroyed, were once interbedded with evaporites.

Carbonate occurs in the following three modes: (1) black, massive dolomite, (2) argillaceous dolomite or dolomitic mudstones and (3) biohermal limestone.

Beds of finely crystalline, black, bituminous dolomite in the Codroy Road Formation occur in the Codroy coastal and lowland areas, drill hole No. 4 on Highlands River (McKillop, 1953a) and as floating inclusions in gypsum in the Codroy section. Two beds occur at Codroy, the thickest, the Black Point limestone, being 10-21 m thick.

The dolomites are usually massive, thick bedded and brecciated at the base of the beds; breccia clasts are cemented by either dolomite mud or spar. Intercrystalline porosity (Choquette and Pray, 1970) is common. Faint lamination is visible in some beds and the tops are invariably hummocky or nodular. Columnar structures, 4 to 5 cm in diameter and several centimetres high, mark the top of the Black Point limestone (Plate 50). They are coated by a pyritized, millimetre-scale, meshlike pattern of fine rectilinear ridges of possible algal origin. Scattered brachiopods and bivalves (*Schizodus sp.*, Bell, 1948)

Plate 50: The top of the Black Point limestone, Codroy Road Formation, Black Point, Codroy coast. The bedding plane is composed of algal heads of black dolomite.

occur in the "limestones". Cavities, up to 50 cm wide, are lined by black lime mud; red sediment displaying geopetal structure is also present. Solution weathering of unknown age has effected one section of the Black Point limestone. Here it has been weathered to a yellow to brown colored, honeycomb-textured rock containing brecciated masses of unaltered, fossiliferous dolomite. The cavities are lined by fine crystalline calcite and siderite and are often partly filled by red and green calcareous mudstone.

Petrographically, the dolomites are composed of brownish dolomite microspar; crystals range in size from 0.005 to 0.01 mm. The microspar is structureless except for some local patches of darker speckling, possibly peloids. Short to branching, 0.1 mm diameter, spar-filled tubules and worm tubes, 0.3 mm in diameter (Plate 51), occur in the dolomites. They possess a concentric-fibrous sheath similar to *Serpula* (Johnson, 1971). Brown colored, radial-fibrous cement has filled the worm tubes and also replaced the dolomite microspar matrix in patches and spherical and linear zones, perhaps reflecting an organic precursor. Scattered ostracods and siliceous and calcareous microspheres also occur.

Fine to wide fractures that cut the dolomite are filled by coarse dolomite spar and some gypsum.

Oncolitic and fossiliferous, argillaceous dolomites and dolomitic mudstones are common in the vicinity of "round valley" and just north of the Anguille Mountains. In both areas, the fine dolomites overlie gray to black mudstones, and lie between red beds. The finely crystalline dolomites are poorly stratified with indistinct lamination which is disturbed by burrows, 1 to 10 mm across. Fauna include goniatites, gastropods, bivalves, crinoids and coiled foraminifera, possibly *Cornuspira* (Mamet, 1970) (Plates 52 and 53). The goniatites found were *Michelinoceras vindobonense* and *Dildoceras avonensis*. The gastropods and bivalves are both small and thin shelled. They include *Lithophagus poolii*, *Pseudophorus minuta* and *Stegoceolia abrupta*. Shell debris is replaced by white spar which also lines vugs in the carbonate mud.

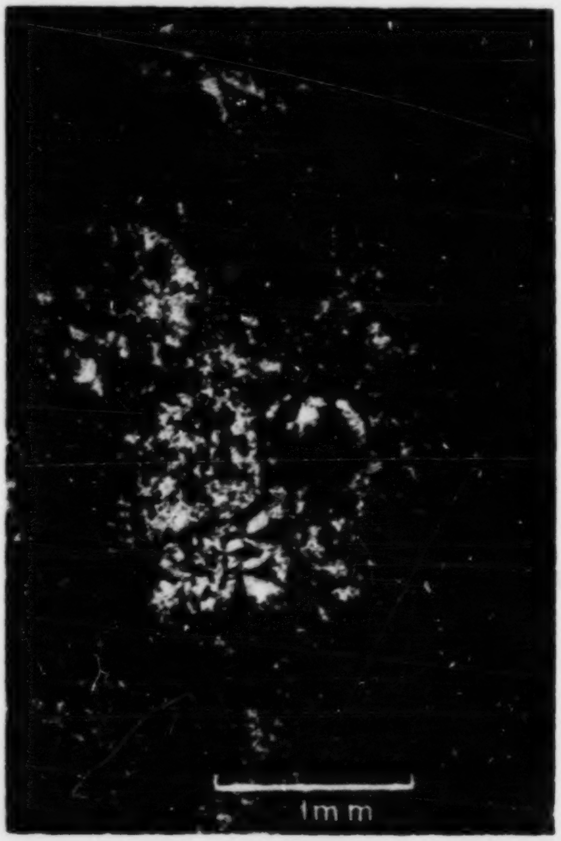
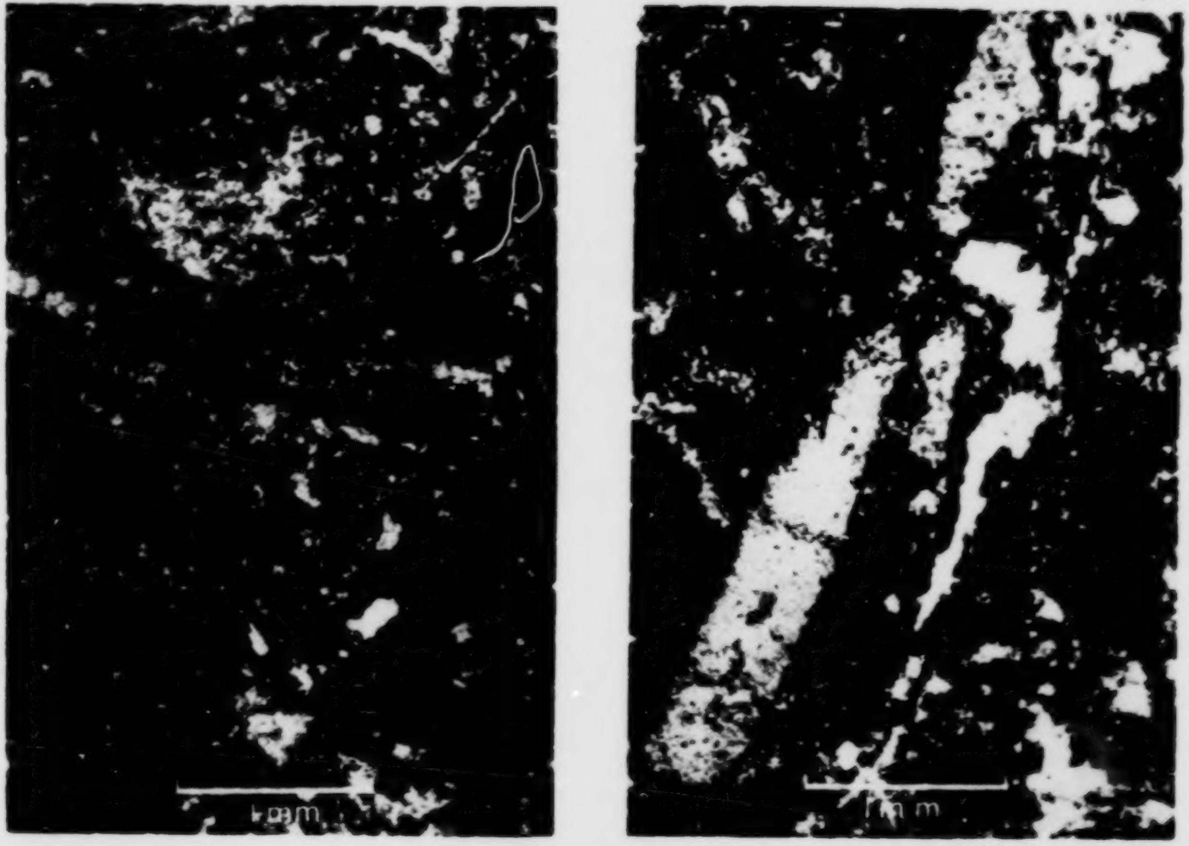


Plate 51: Photomicrograph of dolomite microspar from the Black Point limestone, Codroy Road Formation. The microspar contains worm tubes that are filled by brown, radial-fibrous cement which also appears to affect matrix.

Shelly bioherms composed of brachiopods and bryozoa, augmented by algae, and rare *Paraconularia*, the straight cephelopod *Michelinoceras*, bivalves and gastropods (Hayes and Johnson, 1938), occur at Cormorant Rock, Ship Cove and on the North Branch River near "round valley". The Cormorant bioherm has an open framework with high



Plates 52 to 53: Photomicrograph of black, argillaceous, fossiliferous dolomite from a carbonate bed of the Codroy Road Formation in the "round valley", Codroy lowlands. Most skeletal fragments are replaced by clear microspar although the coiled foramenifera *Cornuspira* (Plate 52) and crinoid ossicles (Plate 53) are readily visible.

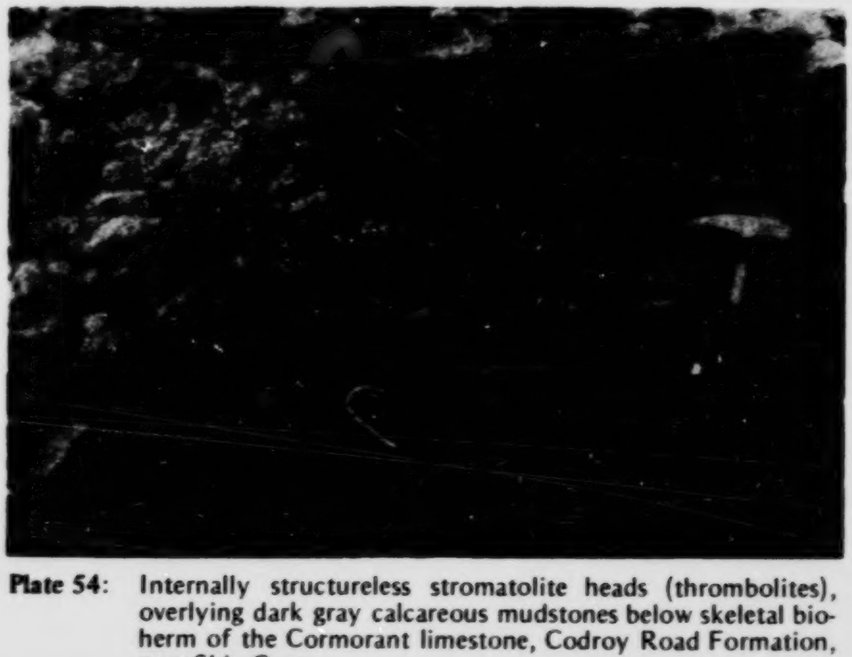
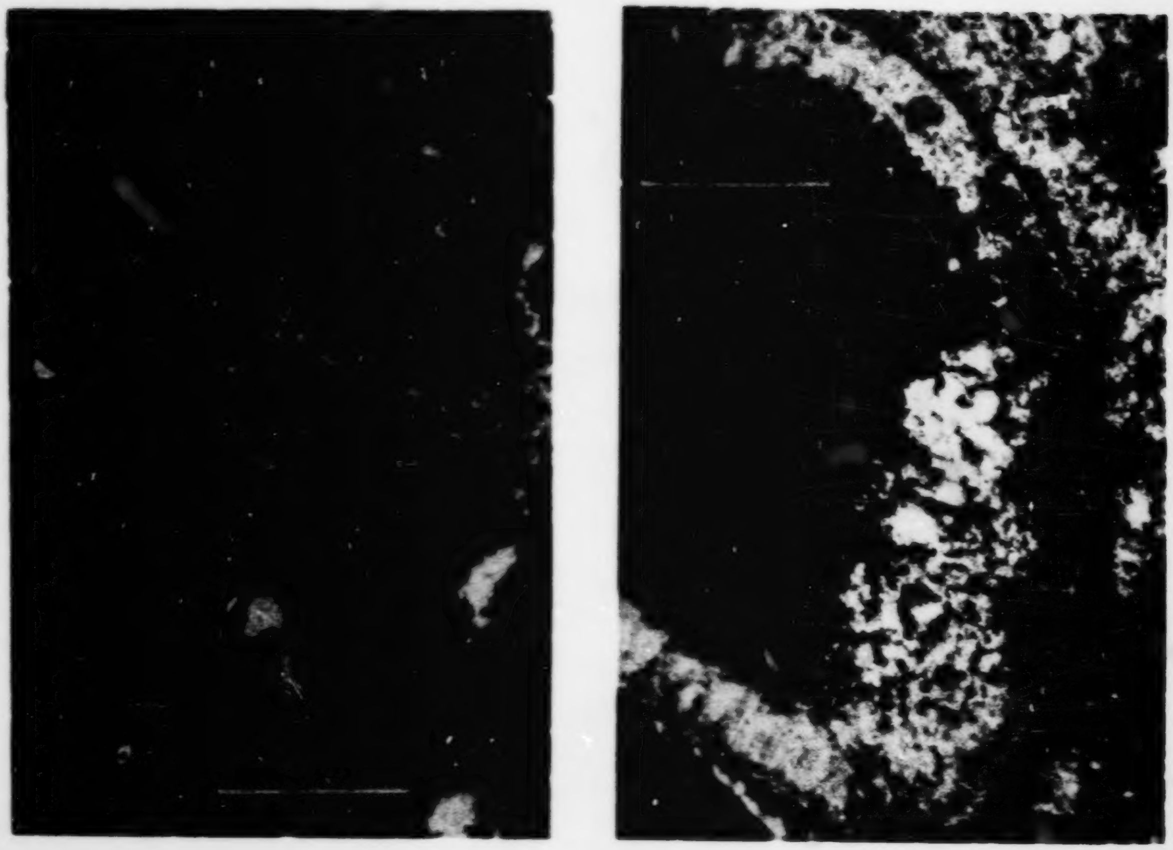


Plate 54: Internally structureless stromatolite heads (thrombolites), overlying dark gray calcareous mudstones below skeletal bioherm of the Cormorant limestone, Codroy Road Formation, near Ship Cove.



Plates 55 to 56: Photomicrographs of the outer zone of the North Branch bioherm, Codroy Road Formation. Reef spaces near bryozoa and inner walls of brachiopods shells are lined by a brown colored fibrous cement (Plates 55 and 56). Pores in bryozoa were filled by a later clear spar cement which also overlays the fibrous cement in the brachiopod shells and fills remaining open spaces in the reef. Mottled lime mudstone is also seen locally.

inter- and intra-particle porosity (Choquette and Pray, 1970) but the "round valley" bioherm contains much carbonate mud within the shelly framework.

The reef at Ship Cove is black in color and composed of limestone. It grew upon a stromatolitic mound 30 cm thick, composed of hemispheroidal heads of internally structureless, black micrite (Plate 54). The mound overlies gray to black mudstones which contain the bryozoa *Batostomella* and the pelecypod *Leptodesma dawsoni*. The bioherm has a maximum thickness of 35 m at Cormorant rock but thins irregularly and rapidly southwestward beneath a thick gypsum deposit that overlaps the bioherm. Northeastward, the bioherm changes laterally to a biomicrite containing many complete brachiopods and resembling the argillaceous dolomitic mudstones of "round valley".

The bioherm on the North Branch River is approximately 7.5 m high with a steep western margin. It lies directly on dark gray mudstones which overlie red and green siltstones and is onlapped and capped by white, gray and black, laminated, selenitic gypsum. The brown dolomitic bioherm consists of a core of partly brecciated, fossiliferous, peloid packstone with low porosity, surrounded by an outer, rubbly, vuggy, fossiliferous zone. Branching bryozoa *Batostomella*, brachiopods (Plates 55 and 56) gastropods, foraminifera, algal lamination, some oncolites and a few ostracods occur in the bioherm.

A complex history of sedimentation and cementation affected the "round valley" bioherm. Brown, fibrous, radiating cements up to 2 mm thick were precipitated (1) in brachiopods, (2) on the outside of, but not in, zooecia pores of bryozoa and (3) within reef spaces of both the core and rim of the bioherm (Plates 55 and 56). The cement postdates the early infiltration of peloid packstones into the brachiopods and the formation of a dark sheath, possibly of algal origin, that encloses the outer surfaces of the bryozoa and beneath which the bryozoa were locally micritized. In some bryozoa, fine spar-filled tubules can be discerned beneath the dark sheath. The cement, however, predates fracture of the shells and deposition of a later clear, blocky spar that filled zooecia and coated fibrous cement in the brachiopods in a manner similar to pendant-like cements (Scholle, 1978). The primary fibrous cement was locally fragmented and recemented by a second generation of fibrous cement which also locally bound the packstone. The remaining chamber porosity in brachiopods as well as breccia and fracture porosity were filled by gypsum.

The history of the bioherm can thus be summarized as follows:

1) There was growth of reef framework of living brachiopods and bryozoa.

2) There was algal encrustation and micritization of bryozoa when the organisms died.

3) Peloid mud was generated *in situ* by reef organisms or mud was trapped by reef framework; mud infiltrated some shells.

4) Brown fibrous cement commenced precipitation within brachiopods, around bryozoa and in reef spaces.

5) The cement was broken and recemented in places; mud was deposited over cements and in turn sealed by later cement.

6) Clear, blocky spar filled bryozoa zooecia and the remaining porosity of brachiopod chambers.

7) Gypsum was precipitated.

The gypsum was introduced into the bioherm when the overlying deposit was laid down.

Interpretation of lithofacies F: The various carbonates of the Codroy Road Formation were deposited in a number of different environmental settings during marine transgression of the subbasin. The black, bioturbated, fossiliferous, dolomitic mudstone and fine dolomites were probably deposited in quiet, muddy, lagoonal areas. The sparse, dwarfed fauna of gastropods and bivalves perhaps indicate that such areas were slightly hypersaline. Carbonaceous laminae in many beds suggest that subtidal algal mat bound the muds in the lagoons. The lagoons were probably not deep because suspended mud in the waters would limit light penetration and restrict algal activity.

The bioherms apparently formed as isolated organic buildups in many places throughout the basin. Small algal mounds typified by obscure internal structure, such as occurs in thrombolites (Aitken, 1967) of subtidal settings, formed a hard, elevated substrate upon which some bioherms were constructed as in the Cormorant limestone. No such substrate, however, is apparent at the "round valley" reef. The bioherms probably grew to an elevation of several to tens of metres above the surrounding lagoon floor, as both the "round valley" and the Cormorant bioherm thin abruptly beneath overlying gypsum beds. The Cormorant bioherm passes both southeastward and westward into lagoonal, brachiopod-bearing muds. The open framework and low mud content of the Cormorant bioherm suggests that it was built in a relatively high energy setting. A lower energy setting is envisaged for the "round valley" buildup which is rich in mud.

The fibrous cements in the "round valley" bioherm compare to submarine cements of modern reefs (Land and Goreau, 1970; Friedman et al., 1974; James et al., 1976). Varying thickness of the fibrous cements, the interlayering of mud and cement and the recementation of fragmented cement all point to cementation over a prolonged time interval.

The massive black dolomites, like the Black Point limestone, give little information to aid in their interpretation. They are poorly stratified and include evidence of algal binding but are generally devoid of fossils. Rare ostracods, calcispheres and polychaete and/or serpulid worms (Johnson, 1971) suggest a hypersaline environment (Marszalek, 1975; James, 1979). Fibrous cement in the worm tubes may reflect early marine lithification. Diagenesis of the original carbonate mud due to hypersalinity may explain the presence of radiating diagenetic fabrics replacing dolomite.

The vuggy, brecciated, limonitic carbonate deposit on the Codroy coastal section, however, is fossiliferous and perhaps was originally a bioherm or skeletal-rich mud mound. The thickness of the Black Point limestone and its absence in other exposures in the Codroy lowlands argues for a mud bank or mound which may have formed southeast of a skeletal barrier. Fine carbonate mud, stabilized by algal binding, accumulated in the lee of this barrier. Salinity generally was higher in the back-barrier environment and hence restricted the fauna to a few salinity-tolerant molluscs, ostracods and serpulid worms. It also probably led to dolomitization of the carbonate mud and formation of radiating cements and diagenetic fabrics.

Paleontology, age and correlative deposits of the Codroy Road Formation

A marine macrofauna from the Cormorant limestone of the Codroy Road Formation are listed in Table 6. Conodonts (von Bitter and Plint-Geberl, 1982) include *Taphragnathus* n.sp. *A*., *Cavusgnathus regularis* type, *?Bispathodus sp.*, *Spathognathodus* n.sp. *A*. and *S. campbelli*. They were recovered from the Cormorant limestone and from black limestones of the northern part of the Codroy coastal section and in the section immediately south of and stratigraphically underlying the Black Point limestone (von Bitter and Plint-Geberl, 1982). The conodont fauna is included in the *Taphrognathus* zone. A restricted fauna characterized by *Cavusgnathus windsorensis* occurs in the Black Point limestone and was assigned to a third and younger conodont zone, the *Cavusgnathus* zone by von Bitter and Plint-Geberl (1982). Using this solitary fauna, they correlated the Black Point limestone with the Heatherton limestone of the overlying Jeffrey's Village Member, Robinsons River Formation. This correlation is not accepted here (see discussion in Paleontology and Age, Jeffrey's Village Member). Rather it is suggested the restricted fauna of the Black Point limestone was environmentally controlled by seawater hypersalinity, the same factor that von Bitter and Plint-Geberl (1979, 1982) claimed as the principal ecological control for *C. windsorensis* in the Ship Cove Formation.

CORMORANT LIMESTONE	FISCHELLS LIMESTONE	CRABBES LIMESTONE	
Compiled from Hayes and Johnson (1938); Bell (1948); and Fong (pers. comm., 1976).	Bell (1948); Fong (pers. comm., 1976)	Grace McGlynn (1980 , pers. comm.); Mamet (1968)	
Brachiopoda *Beecheria davidsoni* *Beecheria latum* *Beecheria milviformus* *Camarotoechia* sp. *Composita* sp. *Diaphragmus tenuicostiformis* *Hartella* sp. nova. *Ovatia lyelli* *Pugnax dawsonianus* *Pugnax* sp. Pelecypods *Aviculopecten lyelli* *Leptodesma dawsoni* Gastropoda *Bulimorpha* sp. indet. Cephalopods *Michelinoceras* sp. Corals *Paraconularia planicostata* Dawson Ectoprocta (Bryozoa) *Batostomella abrupta* *Batostomella exilis* Age: Subzone B	Brachiopoda *Beecheria latum* *Beecheria* sp. *Composita windsorensis* *Diaphragmus tenuicostiformis* *Ovatia lyelli* Pelecypods *Aviculopecten lyelli* *Aviculopecten lyelliformis* *Edmondia rudis* *Grammatodon dawsoni* *Leptodesma dawsoni* *Schizodus* sp. Gastropoda *Naticopsis howi* Age: Subzone B	Brachiopoda *Beecheria* sp. *Camarotoechia acadiensis* *Diaphragmus avonensis* *Ovatia lyelli* *Pugnoides* sp. (Bell) Pelecypods *Sanguinolites niobe* *Schizodus richardsoni* *Schizodus cuneus* Gastropoda *Aclisina acutula* *Bucanopis beedii* *Straparollus minutus* Age: Subzone B or C	Foraminifera, (Mamet, 1968) *Archaediscus* sp. *Archaediscus* du groupe *A. chernoussovensis* Mamet *Archaediscus* du groupe *A. krestovnikovi* Rauzer-Chernoussova *Archaediscus krestovnikovi* Rauzer-Chernoussova *Archaediscus* du groupe *A. moelleri* Rauzer-Chernoussova *Biseriammina* sp. *Brunsia* sp. *Calcisphaera laevis* Williamson *Calcisphaera pachysphaerica* (Pronina) *Climacammina* sp. *Climacammina mississipiana* Conkin *Climacammina* du groupe *C. prisca* Lipina *Climacammina* du groupe *C. simplex* Brady *Cornuspira* sp. *Diplosphaera* sp. *Earlandia clavatula* (Howchin) *Earlandia vulgaris* (Rauzer-Chernoussova et Reitlinger) *Earlandinita* sp. *Endothyra* sp. *Endothyra* du groupe *E bowmani* Phillips *Endothyra* du groupe *E. prisca* Rauzer-Chernoussova et Reitlinger *Endothyra* du groupe *E. similis* Rauzer-Chernoussova et Reitlinger *Endothyranopsis* sp. *Endothyranopsis crassa* (Brady) *Eostaffella* sp. *Eostaffella (?) discoidea* (Girty) cf. *Hedraites* sp. *Hedraites (?) infinitesima* (Beede) *Neoarchaediscus* sp. *Palaeonubecularia* sp. *Palaeotextularia asper* (Cooper) *Palaeotextularia* du groupe *P. consobrina* Lipina *Planoarchaediscus* sp. *"Radiospaerina"* sp. cf. *Saccaminopsis* sp. *Tetrataxis* sp. *Tuberitina* sp. Age: Subzone C

Table 6: Compilation of fossil faunas from the main fossiliferous horizons in the Codroy Road Formation and the Jeffrey's Village Member of the Robinsons River Formation, in the St. George's Bay lowlands.

The *Taphrognathus* conodont fauna is similar to that recovered from limestone beds low in the Miller Creek Formation of Nova Scotia (von Bitter and Plint-Geberl, 1982), whilst the macrofauna is also dominated by species typical of the same Nova Scotia formation (cf. Moore and Ryan, 1976). These faunas are typical of early subzone B of the Windsor Group (Bell, 1929; Moore and Ryan, 1976; von Bitter and Plint-Geberl, 1979). Because they are recorded mostly from the Cormorant limestone, which lies at the top of the Codroy Road Formation, it is probable that much of the fine siliciclastic strata in the lower part of the formation lies within Windsor subzone A. This implies correlation of the lower strata with the Vinland and Tennycape Formations of the Minas subbasin of Nova Scotia (Moore and Ryan, 1976). A startling difference of approximately 1700 m thickness exists between the sequence in the Codroy Road Formation (120 to 300? m) and that of the Vinland-Tennycape Formation (2000 metres).

Depositional environment of the Codroy Road Formation

At the close of deposition of the Ship Cove Formation, intertidal carbonate flats were extensively developed in the south and possibly extreme north of the subbasin with offshore conditions restricted to the Fischells Brook area. This paleogeographic zonation apparently continued during the deposition of the Codroy Road Formation as witnessed by spatial distribution of its constituent lithologies. Cyclic successions of gray beds - evaporites - redbeds, with or without limestone, occur in the southeast. They reflect flooding-dessication-progradation of a marginal marine to alluvial plain environment. In the middle of the subbasin, from north of Ship Cove to Robinsons River, gray siliciclastics of subaqueous origin predominate with important deposits of evaporites. These in turn, pass northwards into evaporites with gray shales and laminated carbonates of probable sabkha and intertidal origin from the area of Flat Bay to the southern edge of the Port au Port ridge.

The structures in the gypsum deposits of the north compare to those of modern evaporite sabkhas in which sulfates grow displacively in intertidal-supratidal carbonate flats. In the central zone, the fine gray siliciclastic sediments with their fine laminations, selenite rafts, halite-crystal pseudomorphs and minor black mudstones were deposited in a narrow, hypersaline lagoon or arm of the sea. Depth of the sea is not known but it probably was not more than 40 m deep. The evaporitic groundwaters in the sabkha flat to the north were supplied by brines from the lagoon by storm flooding (Butler, 1969) and evaporative pumping (Hsü and Siegenthaler, 1969; Hsü and Schneider, 1973). Little evidence is available to construct the history of the lagoon and the evaporites. Nevertheless, the cyclicity in the gray to red siliciclastic rocks, the importance of evaporite deposition toward the top of the Codroy Road Formation and the presence of a shelly, biohermal limestone buildup capped by evaporites generally indicate that changes in water depth, sedimentation rates and salinity must have occurred. Preservation of discontinuity surfaces and of some carbonate beds in the northern evaporite zone also point to acceleration and periodic cessation of evaporite deposition.

In the south, the pronounced cyclicity of the sediments reflects marine flooding that was followed by dessication. Fine alluvium prograded north to impinge upon the margin of the lagoon. This alluvial plain hosted playa lakes and flats in which nodular and crystalline gypsum and halite crystals were deposited. With marine flooding, the alluvial plain was drowned and retreated southeastward. In the expanded lagoon, gray siliciclastics were laid down. As dessication proceeded, smaller restricted lagoons and marginal lakes became isolated from the main lagoon. Deposits of sulfate evaporites were laid down in these small water bodies which may have survived for long periods as they were recharged by storm flooding (Shearman, 1970) or groundwater or brine seepage.

Toward the closing history of the Codroy Road Formation, major floodings brought near normal marine conditions, allowing a limited fauna to thrive at first on the muddy sea floor and thrombolitic algal mounds to form small highs. Bryozoa-brachiopod bioherma1 buildups affected by marine cementation studded the basin at these times but were presumably killed off as the salinity increased and gypsum was precipitated subaqueously. Two or three such episodes occurred in the basin, particularly toward the top of the formation. Where bioherms lay close to the basin margin, they possibly formed barriers behind which thick deposits of stratified, structureless lime muds accumulated. The lagoons hosted a very restricted fauna, including serpulid worms, and periodically became hypersaline resulting in extensive dolomitization.

Robinsons River Formation

Definition and distribution

The Robinsons River Formation is a new name proposed here for a complex succession of 5000+ m of terrigenous clastic rocks with lesser amounts of carbonate and evaporite strata. The succession had not been previously named or subdivided, although it was assigned to the upper Codroy Group by Baird and Cote (1964) and appears to have been considered partly equivalent to the Woody Head and Woody Cove beds by Bell (1948). The formation derives its name from Robinsons River, which crosses the St. George's Bay lowlands.

The Robinsons River Formation underlies both the St. George's Bay and Codroy lowlands but continuity of the succession is broken between the two areas by faulting, folding and the presence of a large tract of Anguille Group strata. The lithologically heterogeneous succession was influenced by the interplay of tectonic setting, climatic conditions and changing depositional environment. Consequently, a variety of rock types have been deposited repeatedly through a great thickness of strata and probably in a time interval of 5 to 8 million years. Rock types also varied with depositional location in the subbasin.

Nevertheless, it is proposed to subdivide the formation into four members based upon lithological characteristics and biostratigraphic information. They are in ascending order the Jeffrey's Village, Highlands, Mollichignick and Overfall Brook Members. The first two occur principally in the St. George's Bay lowlands, while the last two are restricted to the Codroy lowlands. Arkoses of the upper part of the Brow Pond lentil are also placed in the Robinsons River Formation; the lower sequence is retained in the Spout Falls Formation of the Anguille Group.

The Jeffrey's Village Member conformably overlies the Codroy Road Formation. It is best exposed in the St. George's Bay lowlands particularly on the coast and along some of the rivers that cross the lowlands. It is, however, also known from the "round valley", Codroy lowlands. The basal beds of the formation are found in a slightly overturned syncline on the coast near Millville in the Codroy Valley. Float recovered along Brooms Brook also suggests basal beds may be present in tight synclines that occur in the Anguille Mountains.

The basal contact of the Jeffrey's Village Member is placed at the top of the Black Point limestone at Codroy, above the Cormorant limestone and the overlying gypsum at Ship Cove, and at the top of the gypsum located at the railway bridge which crosses Fischells

Brook on the west limb of the Flat Bay anticline. The upper contact is placed at the top of the Crabbes limestone and is best exposed at the mouth of Crabbes River, at Robinsons Head, Stinking Cove and possibly Muddy Hole (Fong, personal communication, 1976; Bell, 1948).

The type section of the Jeffrey's Village Member is compiled from a number of incomplete sections which are correlated by means of the Heatherton limestone (Figure 20 on foldout C). The section begins on Fischells Brook commencing at the railway bridge and continuing to the last exposures 0.7 km from the mouth of the river. The upper part of the member was measured at the coast near Jeffrey's. The two sections are correlated by tracing sink holes associated with gypsum immediately above the Heatherton limestone. The sequence above this limestone marker is also well exposed along the coast from Rattling Brook to Robinsons Head but there it has not been measured.

The Highlands Member, previously called the Highlands sandstone member by Baird (1959), conformably overlies the Crabbes limestone. The type section is located along the coast south of Crabbes River and continues to the youngest beds exposed in the St. David's syncline; the succession then continues beneath the shallow waters of St. George's Bay. Equivalent but undivided strata occur inland east of the Barachois synclinorium (Fong, personal communication, 1976) and a thick sequence of redbeds penetrated in a drill hole at St. Teresa (Amax Exploration, 1976) is also placed in the member.

To date, the Mollichignick Member is known only from the Codroy lowlands where it is named after Mollichignick Brook. The type section (Figure 21 on foldout C) occurs along the North Branch of the Codroy River and the Grand Codroy River. The stratigraphic base is not seen and the basal contact, seen 3.2 km north of the community of South Branch, is everywhere a major, northeast trending fault. The section is exposed downstream along the Grand Codroy River as a southeastward dipping monoclinal sequence to the point where the upper contact with the Overfall Brook Member is reached, approximately 750 m northeast of the confluence with Overfall Brook. The Mollichignick Member extends as far southeast as the vicinity of the Codroy Provincial Park, where it terminates against a fault zone trending east-west between Stormy Point and Little Codroy Pond. The member also continues northeast from the type section into the ground between the North and South Branches of the Grand Codroy River. Here it terminates south of Bald Mountain against an east trending fault system along the North Branch River and also against the Long Range fault to the southeast.

The Overfall Brook Member occupies the core of a southeast plunging, locally overturned syncline that formed adjacent to the Long Range fault. It is terminated against the major fault that is postulated to strike from Stormy Point to Little Codroy Pond.

The type section (Figure 22) is located along Overfall Brook, the tributary stream that lends its name to the member. Exposures are also found in other incised streams northeast of Overfall Brook.

The conformable base of the member is placed at the first thick, continuous succession of arkosic rocks overlying the finer, red and gray beds of the Mollichignick Member. The basal contact is exposed 750 m north of the mouth of the Overfall Brook in the bed of the Grand Codroy River.

Rocks of the Brow Pond lentil that are assigned to the Robinsons River Formation are found in a west-southwest dipping sequence that forms the high plateau near Brow Pond and Big Otter Pond in the northeast corner of the subbasin. The succession overlies a local unconformity in the lentil. The unconformity, mapped using airphotographs, can be traced from Brow Pond south to Big Otter Pond. Contacts with other parts of the Codroy Group and the younger Barachois Group are generally faulted. The Barachois Group may, however, stratigraphically overlie the strata of the Brow Pond lentil north of Fischells Brook.

Thickness

A cumulative thickness of approximately 5000 to 6200 m is likely for the Robinsons River Formation. The two lower members in the St. George's Bay lowlands comprise 2400 to 3400 m of the succession, while a thickness of 2500 to 2700 m is represented by the upper members in the Codroy lowlands.

The Jeffrey's Village Member is approximately 1400 m thick in the type section. The member may thicken to 2000 to 2100 m in the vicinity of salt deposits that occur southwest of the Flat Bay anticline (Hooker Chemical Corporation, 1968b, 1971). A basin, filled with 5000m of dominantly Codroy Group strata, lies beneath St. George's Bay (Spector, 1969; Golden Eagle Developments Ltd., 1975). The presence of a possible salt structure in the basinal deposits suggests that a part of the sequence belongs to the Jeffrey's Village Member.

The type section of the Highlands Member was measured at 884 m with an additional 200 to 500 m likely offshore (Bell, 1948; Baird, 1959).

The succession of the Mollichignick Member is calculated from the type section to be at least 2275 m thick. The Overfall Brook Member is at least 345 m thick in the type section.

General lithology

The succession found in the Robinsons River Formation is described for each member and is followed by detailed descriptions of lithofacies that occur in the formation. The successions found in the St. George's Bay and Codroy lowlands are illustrated in Figures 20 and 21 respectively. The characteristics and relative importance of lithofacies in each member are tabulated in Table 7.

Jeffrey's Village Member

The Jeffrey's Village Member consists of red and gray shales, mudstones, siltstones, sandstones and conglomerates interbedded with carbonates and evaporites. The latter include anhydrite, gypsum, halite and potassic salts.

Sedimentary rocks of the Jeffrey's Village Member can be divided conveniently into two parts, which are separated by the Fischells limestone (Figure 20). Below the limestone, the succession contains dominantly drab colored, fine siliciclastic rocks, some evaporites and lesser redbeds. The upper sequence consists of red siliciclastics with several carbonate units and minor evaporites.

The lower sequence from Ship Cove southwest to Codroy commences with fine redbeds with some carbonates which are brecciated (Codroy breccias, Bell, 1948). In the north, near Fischells Brook, however, the lower sequence is dominated by thin bedded, gray, green, black and brown mudstones, and siltstones with some fine green-gray sandstones and fine redbeds. They comprise mostly lithofacies N, O, P, and Q and lesser amounts of lithofacies M, B and A. Massive to finely laminated, gray, green and black mudstones and green-gray, ripple cross-laminated siltstones dominate thick sections of the lower sequence. They are associated with two major units of green-gray, fine grained sandstones that are rich in green mudclasts and large trough-crossbeds. The rest of the lower sequence is composed of brown, structureless silty mudstones and ripple cross-laminated and laminated

TABLE 7: SUMMARY OF DISTRIBUTION AND CHARACTERISTICS OF SEDIMENTARY LITHOFACIES, ROBINSONS RIVER FORMATION

LITHOFACIES	DISTRIBUTION				COLOR				GRAIN SIZE				SEDIMENTARY STRUCTURES + ORGANIC REMAINS																
	JV	H	M	OB	JV	H	M	OB	JV	H	M	OB	Sc	XB	PS/L +pl–	X L	C RD	MASS	CB	DEF	MC	EV MD	PEB	INT CL	PL RT	PL DEB	BIOT	FOSS
A. SILTSTONE	C-A	C	C-A	R	Rd Gn	Rd	Rd Gy Gn	Rd	-	-	-	-	R	R	R C	C	R	A	-	R	C	R-U	-	-	U	-	R-C	-
B. FINE SANDSTONE	C	R	C	-	Rd Gy	Rd	Gy Rd	-	C slt-F ss	VF ss	C slt-F ss	-	U-C	R	C C	C	C	R	-	C	C	-	-	U	U	U	U	-
C. PLANAR-STRATIFIED SANDSTONE	C	R	A	-	Rd Gy	Rd	Gy Rd	-	VF-F ss	VF-M ss	F-VF ss	-	U-C	U	A - C A	U	C	-	-	U	-	-	R	R	U	C	U	-
D. THICK, GRADED AND UNGRADED SANDSTONE	C U	A R	C R	-	Rd Gn-Gy	Rd Gy Ye	Gy Rd	-	VF-C ss	VC M ss	M-VF C/M-M/F ss	-	A	C-A	C U	C	U	-	R	U-C	-	-	U	U-C	U	R-C	R	-
E. PEBBLY, ARKOSIC AND MUDDY SANDSTONE	R-U	-	C	A	Br-Rd	-	Gy Br Rd	Rd Br Pk Wh	-	-	VC-M ss	VC M ss	A	C	U -	U		C	C	U	-	-	C	U	-	R	-	-
F. CALICHE LIMESTONE NOD. CEM. MASS.	R R U	C U U	C C C	-	Gy	Gy Pur	Gy	-	-	-	-	-	-	-	- -	-	-	-	-	-	-	R	-	-	R	-	-	-
G. INTRAFORMATIONAL CONGLOMERATE	-	R	R	-	-	Gy	Rd Wh	-	-	-	-	-	C	C	- -	-	-	C	C	-	-		R	C	-	-	-	-
H. GRAY, CARBONACEOUS AND MICACECUS MUDSTONE-SILTSTONE	-	-	C	R	-	-	Gy Bk	Gy Bk	-	-	C slt-M ss	C slt-M ss	R	-	R -	C	-	C		R	R	-	-	-	R	C	R	-
I. INTERCALATED CALCAREOUS MUDSTONE-CARBONATE-MICACEOUS SANDSTONE	-	-	C	-	-	-	Gy Bk	-	-	-	C slt-M ss		U	U	C -	C	-	C	-	U	R	-	-		-	C	U-C	U
J. PEBBLY MUDSTONE	R	-	-	R	Rd	-	Gy	-	-	-	-	-	R	-	- -	-	-	C	C	-	-	-	C	R	-	-	C	-
K. RED CALCAREOUS SHALY SILTSTONE	C	-	U	-	Rd	-	Rd	-	-	-	-	-	R	-	U -	U	-		-	-	C	R	-	-	U	-	-	-
L. BEDDED GRAY MUDSTONE-SILTSTONE/SANDSTONE-CARBONATE	R	R	R-C	-	-	Gy Wh	Gy Rd	-	-	C slt-VF ss	C slt-VF ss	-	U	R	U U	C	-	-	-	U	U	U	-	R	-	U	C	U
M. GRAY SHALE-SILTSTONE/SANDSTONE	U	-	U	-	Gy	-	Gy	-	C slt-F ss	-	C slt-M ss	-	U-C	U	C C	C	-	-	-	U	U	U	-	-	-	U-C	C	C
N. VARICOLORED MUDSTONE	C	-	-	-	Bk, Bl-gy, Gn-gy, Gn, Rd	-	-	-	-	-	-	-	-	-	- C	R	-	C	-	C	U	U-C	-	-	-	-	-	-
O. HALITE-BEARING SILTSTONE-SANDSTONE	C	-	-	-	Br-Rd Gy	-	-	-	C slt-VF ss	-	-	-	U-C	U	U C	C	U	C	-	U	C	C	-	R	R	-	-	-
P. GREEN-GRAY MUDSTONE-SILTSTONE	C	-	-	-	Gn-gy Gn	-	-	-	C slt	-	-	-	R	U	- -	C	C	C	-	U	U	U	-	-	-	-	-	-
Q. CROSSBEDDED SANDSTONE	C	-	-	-	Gn-gy	-	-	-	VF ss-F ss	-	-	-	A	A	C -	C	C	-	-	U	U	-	U	C	-	U	-	-
R. MARINE CARBONATE	C	-	-	-	Gy Rd	-	-	-	-	-	-	-	-	-	R -	U	-	C	-	-	U	U	-	-	-	R	C-U	A-R
S. EVAPORITE	U	-	-	-	Wh	-	-	-	-	-	-	-	-	-	R -	-	-	-	-	-	-	-	-	-	-	-	-	-

KEY

R = Rare, U = Uncommon, C = Common, A = Abundant; JV, H, M, OB = Member Initials; Rd = red, Gy = grey, Gn = Green, Gn-gy = green-gray, Br = brown, Bk = black, Pk = pink, Pur = purple, Wh = white, Ye = yellow; C slt = Coarse siltstone, VF, F, M, C, VC, ss = sandstone grain size; Sc = scour, XB = crossbeds, PS/L = planar stratification/lamination ± parting lineation (pl), XL = Cross lamination, CRD = climbing ripple-drift, Mass = massive, CB = Crude bedding, DEF = deformed bedding, MC = mudcracks, PL RT = plant rootlets, BIOT = bioturbation, CALICHE LIMESTONE; NOD = Nodular, CEM = cemented bed, MASS = massive and laminar, FOSS = fossils, PL DEB = plant debris siltstones; very fine sandstones are also present intercalated with finely laminated, varicolored mudstones. Small halite pseudomorphs are common in some mudstones and siltstones; dessication structures also occur. Rippled sandstones, bar-shaped sandstone bodies, some red siltstones and planar crossbedded sandstones are also present.

The evaporites in the lower Jeffrey's Village Member consist of anhydrite, gypsum, halite, and some carnallite, sylvite and polyhalite (Hooker Chemical Corporation 1968a, 1972, 1973). Potassic salt horizons occur at the top of the 390 m thick Fischells Brook salt deposit. The salt is relatively free of clays but contains variable amounts of anhydrite and gypsum. The salt deposits at Robinsons and St. Fintan's are well bedded and contain many interbeds of fine gray and some red siliciclastics. Two salt horizons, separated by gray shales, occur in the Robinsons deposit. Potassic salts are distributed at several levels within the intercalated salt and mudstones that form the St. Fintan's and Robinsons salt.

White, massive and selenitic gypsum (Bell, 1948) is exposed near Plaster Cove. It lies near the base of the evaporite section about 100 m beneath the main salt sections.

Above the Fischells limestone, the Jeffrey's Village succession is approximately 785 m thick. It includes greater than 50% fine beds composed of red, structureless siltstones and red, calcareous, shaly siltstones (lithofacies A and K) which may contain mudcracks, halite pseudomorphs and some caliche. The fine redbeds are interbedded with sheet deposits of fine grained sandstones (lithofacies B and C) which generally display planar stratification and ripple cross-lamination. Thicker red sandstones (lithofacies D) contain crossbedding and planar stratification; massive to crossbedded conglomerates and pebbly sandstones (lithofacies E) are interbedded with the ubiquitous red siltstones. The latter contain significant caliche limestones in the middle of the sequence. Pebbles in the conglomerate (see Table 8) were derived from the Cambro-Ordovician platformal sequence north of the subbasin and from granites and silicic volcanics like those of the Topsails Igneous Complex to the southeast of the subbasin. Overall, the succession is sandier in the stratigraphic interval from the Fischells limestone to a point 130 m above the Heatherton limestone. For the next 150 m the succession is dominated by red siltstones and thin, fine grained sandstones but gradually coarsens upward not only towards the top of the member but apparently also northward and eastward over the same stratigraphic interval.

A variety of carbonates (lithofacies R), fossiliferous, bioturbated and mildly evaporitic gray shales, rippled and planar laminated siltstones and sandstones (lithofacies M) and very minor gypsum and celestite (lithofacies S) are intercalated in the redbeds. Some fine red sandstones and siltstones with abundant ripple marks, local bioturbation and planar stratification lie immediately above or are associated with the carbonates (Figure 27; JVL-2, Figure 31).

The carbonates in the Jeffrey's Village Member are buff weathering, argillaceous and dolomitic limestones or gray, purer limestones. Lime mudstones, fossiliferous and peloidal wackestones and packstones, algal and stromatolitic limestones and some oolitic grainstones are all represented. Secondary dolomites and calcretes are also common. The carbonates decrease in thickness upward as they change from skeletal packstones and lime mudstones and shales in the lower units to oolite and stromatolite-dominated upper units. Thin evaporites (gypsum zone D of Bell, 1948) occur with the algal carbonates of the Heatherton limestone. This unit has been extensively replaced by red dolomite. Fossiliferous and oncolitic, clean gray limestones interbedded with gray shales form the Crabbes limestone; i.e. the top of the member.

Unlike the lower evaporitic succession, the upper, dominantly alluvial sequence appears to be fairly uniform in thickness in the St. George's Bay area. Carbonate strata in the "round valley" area suggest the upper unit extended into the northern part of the Codroy lowlands.

Highlands Member

The upward coarsening of the red fluviatile rocks in the top of the Jeffrey's Village Member culminated in the deposition of a 1200+ m thick sequence of red, minor gray and some yellow sandstones and red siltstones in the Highlands Member of the St. David's syncline. Conglomerates and argillaceous, pebbly sandstones were laid down in time-equivalent strata to the east and north (Fong, personal communication, 1976). Brown-red conglomerates and pebbly sandstones also compose the St. Teresa drill hole (Amax Exploration, 1976).

The succession in the St. David's syncline consists dominantly of repetitive fining-upward sequences, 5 to 15 m thick, composed of intraformational conglomerates, crossbedded and planar laminated sandstones (lithofacies D) and red siltstones (lithofacies A) with some caliche (lithofacies H). The sandstones are generally friable and calcareous. Green reduction spots are particularly common in the sandstones. Most caliche limestones are nodular; four caliche limestone beds, 90 to 210 cm thick, occur in the middle part of the member. Caliche and red siltstones were reworked into channel-bound intraformational conglomerates (lithofacies G). Some red sandstones in the succession may have an aeolian origin.

Coarsening-upward sequences of green to reddish-green shales, siltstones, and fossiliferous, bioturbated, rippled and laminated sandstones occur at the base of the member immediately above the Crabbes limestone (Figure 27). Approximately 200 to 310 m above the base of the Highlands Member in the type section, two thin units of clean, white to green, current- and wave-rippled sandstones and siltstones (lithofacies M) are interbedded with wavy bedded, fossiliferous, laminated, mudcracked gray limestones.

Mollichignick Member

The 2300 m succession of the Mollichignick Member (Figure 21 on foldout C) is composed mostly of red siltstones (lithofacies A), red to gray micaceous sandstones (lithofacies B) and stratified sandstones (lithofacies C). Also present are ungraded and fining-upward sequences consisting of thick gray sandstones (lithofacies D) intercalated with red siltstones. Argillaceous and arkosic pebbly sandstones (lithofacies E) occur interspersed in the succession with many of the other lithofacies and form thick basin-fill sequences close to the southeast margins of the subbasin. Units of gray, lacustrine mudstones, carbonates and micaceous sandstones and siltstones (lithofacies H and I) are important contributors to the lower 1000 m of the Mollichignick Member. Marine carbonates, shales and sandstones, which are characterized by thin coarsening-upward sequences, some shelly fossils, ripple-marks and bioturbation (lithofacies L, M, Q, and K) are found in the middle of the member, 1200 to 1700 m above the base.

The lowest part of the member is dominated by a series of coarsening-upward megasequences, 45 to 220 m thick. They are composed of gray beds (lithofacies H and I), red siltstones (lithofacies A) gray and red sandstones (lithofacies C) and are capped by pebbly and argillaceous, arkosic sandstones (lithofacies E). Together these megasequences form a thick, upward coarsening, basin-fill sequence.

Above the megasequences, thick gray sandstones (lithofacies D) and caliche-bearing red siltstones (lithofacies A and F) become widely developed in the Codroy lowlands. Lithofacies C and E (planar stratified sandstones and pebbly sandstone and conglomerate) occur stratigraphically higher in the member toward the centre of the subbasin, whilst lithofacies E conglomerate and pebbly sandstones were laid down at the margins. In the middle of the succession, shales, siltstones and rarer carbonates (facies A, K, L and M) dominate the sequence.

Overfall Brook Member

The Overfall Brook Member (Figure 21, Figure 22) is composed mostly of red, pink and brown, thick bedded, massive and crossbedded, pebbly and arkosic sandstones and grits, argillaceous sandstones and minor conglomerates. The coarse sequence in the lower part of the member is interrupted at 5 to 30 m intervals by units of fine, gray mudstones, siltstones and pebbly mudstones (lithofacies H and J) together with some red siltstones and sandstones. Above this, the fine sediments are generally infrequent, and decrease upward concurrent with an increase in sand- and pebble-sized grains (Figure 22).

Description of lithofacies

Eighteen major lithofacies are defined in the Robinsons River Formation (Table 7).

(A) SILTSTONE LITHOFACIES

Description of lithofacies A: This lithofacies is composed of dominantly red colored, structureless, hackly weathering siltstones or intercalated structureless and current-laminated siltstones (Plates 57 and 58). It groups together indiscriminately all lithologies of clay to silt grade. The facies, which occurs in units 20 cm to 14 m thick, is most abundant in the Jeffrey's Village Member, forming more than 60% of some parts of the succession; it is also an important element in other members.

The massive siltstones are generally uniform, poorly sorted deposits that exhibit some crude bedding and faint lamination. Current-deposited siltstones, which are 5 to 15 cm thick, are intercalated both sharply and gradationally within the massive siltstones. They have a coarse silt grain size and exhibit both flat and cross-lamination. Mudcracks, plant rootlet impressions and caliche nodules are preserved locally. In the Mollichignick Member, the rootlets form a creeping, spidery, open network across bedding surfaces.

Halite pseudomorphs are common in mudcracked siltstone beds of the Jeffrey's section of the Jeffrey's Village Member. They are preserved as cubes, irregular cubes, and hopper pyramids, 0.2 to 5 cm in size. The present composition of the pseudomorphs is carbonate, siltstone, granulose and porous gypsum, or layered gypsum and siltstone. Preferred corner growth (Shearman, 1978) and interference of sediment (Handford and Moore, 1976) produced skeletal arms up to 5 cm long projecting from crystal corners. Arching of sediment over projecting corners of some crystals also occurs.

A number of discontinuous beds, 1 to 3 cm thick, of pink, fibrous gypsum also occur in gray and red siltstones of the Jeffrey's Village Member. The layers are locally nodular and are enterolithically folded (Shearman, 1978).

Interpretation of lithofacies A: The fine red sediments of this lithofacies are interpreted to be flood plain deposits. (Allen, 1965a; Collinson,

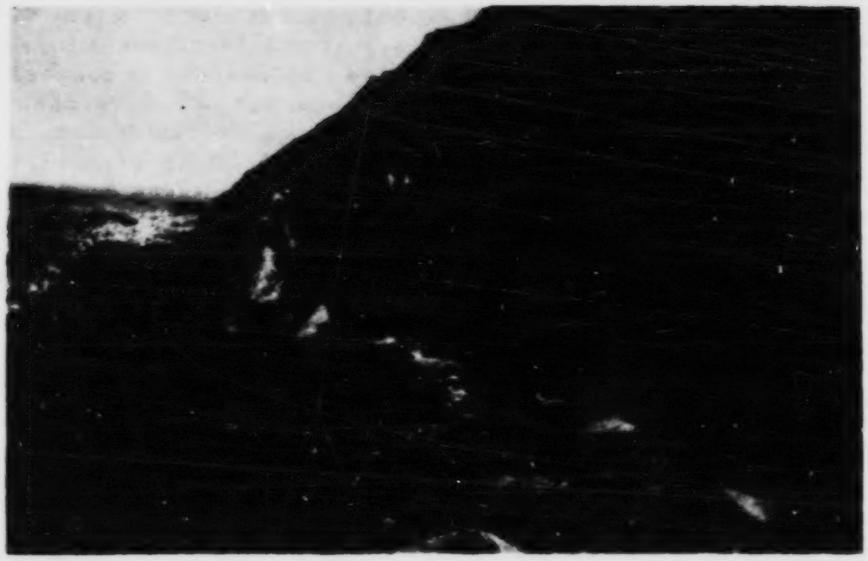


Plate 57:. Thick red siltstone unit separating two lithofacies D sandstones in the Highlands Member, Robinsons River Formation. Grooves are carried on the base of the upper sandstone and small caliche nodules occur at two levels in the siltstone. Measuring stick 1 m long.

Plate 58: Thick red siltstones intercalated with sheet sandstones of lithofacies B, Jeffrey's Village Member, Robinsons River Formation, Jeffrey's coastal section.

1978a). Where associated with thick channel sandstone (Figures 23 to 25, Foldout D), the siltstones were laid down as vertical accretion deposits following overbank flooding of low-lying areas between channels. The crudely bedded siltstones were deposited from suspension, and the ripple cross-laminated siltstones were deposited by gentle currents flowing in the lower flow regime (Harms and Fahnestock, 1965; Simons et. al., 1965; Southard, 1975). Dessication of the floodplain siltstones was common. Spidery, creeping rootlet patterns suggest vegetation flourished locally; nodular caliche formed in soil horizons. Both caliche (Gile et. al., 1966) and the spidery plant rootlet systems (Sargaent, 1975) are indicative of semiarid climatic conditions.

Where the siltstones are interbedded predominantly with fine sandstones of lithofacies B and locally with marine carbonates (Figure 20), a distal position on an alluvial and/or coastal plain is envisaged. In this environment the muds and fine sandstone sheets were deposited by small streams, sheet floods and possibly by aeolian processes.

Halite pseudomorphs and gypsum layers in the facies in some sections of the Jeffrey's Village Member suggest that some of the siltstones accumulated locally in playas. Features such as enterolithic folding of gypsum layers, interlayering of sediment and evaporite in halite pseudomorphs, arching of sediment over the corners of the halite crystal corners and growth of skeletal arms out of halite crystals (Smith, D.B., 1971; Handford and Moore, 1976; Shearman, 1978) indicate both evaporite phases formed mainly displacively in brine-saturated muds.

(B) FINE SANDSTONE LITHOFACIES

Description of lithofacies B: Lithofacies B consists of argillaceous and micaceous, gray and/or red sandstones that are fine or very fine grained. The facies occurs in all but the Overfall Brook Member. Either it is only interbedded with lithofacies A siltstones (Sections A-D, Figure 23), or else it forms sequences with both lithofacies A siltstones and graded sandstones of lithofacies D (Figure 23, Sections A to E; Figure 24, Section E; Figure 25, Sections A to C).

Sandstones associated only with lithofacies A siltstones are commonly graded, very fine grained deposits, 20 to 100 cm thick. They form sheets that lie erosively or sharply upon red siltstones (Plate 58) and commonly contain layers of sand-sized mudchips (Figure 23, Section A). Ripple cross-lamination occurs with rib and furrow, and planar lamination which is associated with parting lineations. Shallow to deep (3 to 36 cm) scours, some filled by red siltstone, cut through some of the sheet sands. Mudcracked siltstone partings occur between beds and toward the top of sandstone beds.

Fine sandstones associated with graded sandstones of lithofacies D are either graded or ungraded, poorly sorted deposits that have sheet, lenticular and rarely bar-shaped forms (Plate 59). The sands are characterised by basal and internal scours, climbing ripple-drift (Plate 60), convolute bedding, and lenses of structureless sand; planar stratification and crossbedding are also present. Mudcracked mudstone partings and flat, coarsely laminated, silty mudstone beds, 3 to 15 cm thick, occur between sandstone beds.

Paleoflow direction of ripple-drift in sandstones of the second association is generally perpendicular to that of crossbeds of lithofacies D sandstones.

Interpretation of lithofacies B: The fine sandstones are interpreted as deposits of small streams and crevasse-splays, deposited in distal parts of the alluvial plain or near river channels.

Plate 59: Sheets and lenses of fine sandstone (lithofacies B) interbedded with lithofacies A siltstones in Jeffrey's Village Member, Robinsons River Formation, Jeffrey's coastal section.

Plate 60: Fine sandstones of lithofacies B, Jeffrey's Village Member, Robinsons River Formation, north bank of Robinsons River near route 63 road bridge. Bed is composed mostly of climbing ripple-drift. Sedimentary structures locally deformed by soft-sediment deformation to form structureless sandstone in the middle of the bed. The sandstone bed is intercalated with coarsely interlaminated siltstones and sandstones.

The graded sheet sandstones interbedded with lithofacies A siltstones in the Jeffrey's Village Member are probably deposits of shallow, ephemeral stream channels that crossed the distal alluvial plain. Small scale, linguoid, lunate or cuspate ripples (darms, 1975) forming cross-laminated sands migrated along the channels under lower flow regime conditions (Simons et al., 1965). Ephemeral deposition is indicated by red siltstone plugs and mudcracked siltstone parting within the sandstones.

Fine sandstones associated with lithofacies D sandstones have characteristics that compare to those of channel levees or crevasse-splay deposits (Reineck and Singh, 1975; Ray, 1976; Collinson, 1978a). The predominance of climbing ripple-drift in many of the sheet sandstones suggests that abundant fine sediment was rapidly deposited from suspension during overbank flooding (McKee, 1965). Interbeds of flat, coarsely laminated silty mudstone and dessication structures in both mudstone interbeds and drapes suggest that thick sequences composed of these lithofacies accreted over many flood-cycles of overbank sedimentation.

The bar-shaped sand deposits, that are also characterized by climbing ripple-laminations, are probably crevasse-splays deposited near the point at which flood waters breached a levee.

(C) PLANAR STRATIFIED SANDSTONE LITHOFACIES

Description of lithofacies C: This lithofacies forms a particularly important element of the Mollichignick Member but also occurs in the Jeffrey's Village Member. The facies is formed of fining-upward sequences of gray or red sandstone and red siltstone (Figure 23, Sections B and C; Figure 25, Sections D and E).

In the Jeffrey's Village Member, buff to red, fine and very fine sandstones, 10 to 50 cm and rarely 200 cm thick, are intercalated with red siltstones. Flat planar lamination with parting lineations, some climbing ripple-drift, and sharp flat bases and tops typify the sandstones.

Dominantly gray, fine to very fine grained sandstones rich in mica and fine carbonaceous plant detritus compose this lithofacies in the Mollichignick Member. The sandstones occur in units 1 to 4 m thick in two facies associations. The first association (Figure 25, Section D) consists of one or more sandstone units interspersed every 4 to 10 m in red siltstones. In the second association (Figure 25, Section E), stratified sandstones are separated by only 20 to 200 cm of siltstone, and many form megasequences up to 130 m thick.

Bases of sandstone beds in the Mollichignick Member are generally sharp and planar or locally irregular (Plate 61), but in some instances they are gradational with the underlying siltstone. The sandstones are composed almost exclusively of thin stratification and lamination that is either planar, or broadly undulating (Plate 61). Parting lineations are generally absent, possibly because of the high mica content. Bedding is locally inclined where it conformably overlies steeply inclined, generally planar scours. The scours truncate underlying thin beds and pass out into slightly discordant planar surfaces within the main body of the sandstones.

Rare crossbedding occurs near the bases or tops of the sandstone units. Elliptical scours, 1 to 3 m wide and 8 to 30 cm deep, are filled symmetricall by thin stratification; complete geometry of the crossbeds is uncertain due to the nature of the outcrops.

Ripple cross-lamination and climbing ripple-drift of types A and B (Jopling and Walker, 1968) plus low amplitude sinusoidal lamination occur toward the top of some units. The top sandstones, which are red, pass up into red siltstones which also display crude

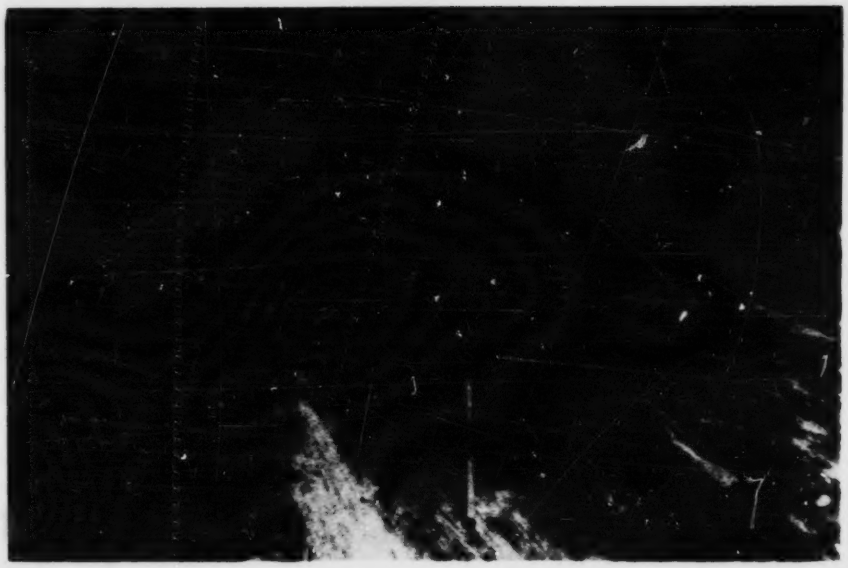


Plate 61: Planar stratified, gray, micaceous, fine sandstones of lithofacies C, Mollichignick Member, Robinsons River Formation, overlying a locally scoured base (arrow). Bed of Grand Codroy River, 2 km downstream from South Branch.

Plate 62: Tubular bioturbation in the top of reddish gray sandstone of lithofacies C, in the Mollichignick Member, Robinsons River Formation. The tubes are infilled by red siltstone of overlying bed. Grand Codroy River near Limestone Brook.

planar lamination and local scour and fill. Coarse, tubular, silt-filled molds (Plate 62) are common in the tops of sandstone units, and spidery plant rootlets occur in overlying laminated siltstone.

Interpretation of lithofacies C: The sandstones of this lithofacies, although they fine upward, are not characteristic of classical, fining-upward fluvial cycles, typified by channel scour bases, abundant trough-crossbedding and basal lag of mudclasts (Allen 1964a, 1965 a, and b). Lithofacies C sandstones are sheet-like and characterized by horizontal thin stratification and lamination overlying only locally erosive bases. The geometry and bedding compares to that found in crevasse-splay (McKee et al., 1967; Coleman, 1969), sheetflood or ephemeral, low sinuosity stream deposits (Williams, 1971; Picard and High, 1973; Tunbridge, 1981a and b).

Although parting lineation is rare, the Mollichignick sandstones were probably deposited from currents flowing in the upper flow regime (McKee et al., 1967). Abundance of micas, especially in the Mollichignick sandstones, suggests that the fine sandstones were deposited rapidly from suspension with no time for mineral sorting or alignment. Rapid deposition of sand during the late waning stages of flood (McKee et al., 1967) is indicated by climbing ripple-drift (McKee, 1965) at the tops of some sandstone units (see also Williams, 1971). The presence of low angle scour surfaces within the deposits suggests a number of flood surges which were locally erosive.

The thick lithofacies C deposits of the Mollichignick Member were probably sheetwash or shallow ephemeral stream deposits generated on the lower slopes of alluvial fans by flashfloods. (Heward, 1978b; Hardie et al., 1978). Sediment from the inner slopes of the alluvial fans was reworked (Blissenbach, 1954; Hooke, 1967) and redeposited at the toe of the fan or on the adjacent alluvial plain, perhaps as a sandflat apron (Hardie et al., 1978). Tunbridge (1981a and b) showed the importance of a similar facies in redbeds of the Old Red Sandstone of Wales and southwest England. He concluded that the deposits formed in low sinuosity sand-bed channels. These merged downslope into silty sheet floods of an extensive alluvial plain that in turn was bordered by a muddy floodplain. He drew an analogy to the geomorphology of the Eyre Basin of South Australia.

Thinner sand sheets of the Jeffrey's Village Member formed when flood-stage rivers carrying abundant fines in suspension escaped the confines of their channels. This occurred either by levee breaches (Allen, 1965a) or when the dimensions of channels were inadequate to confine the magnitude of floodwater and a general overflow of the banks occurred (McKee et al., 1967; Baker, 1977).

(D) THICK, GRADED AND UNGRADED SANDSTONE LITHOFACIES

Description of lithofacies D: Fining-upward, ungraded, and some coarsening-upward sandstones, mostly 0.5 to 13 m thick, form important parts of the Jeffrey's Village, Highlands and Mollichignick Members (Figure 23, Sections D to G; Figure 24, Sections B to F; and Figure 25, Sections A to C). Multistory sandstone sequences up to 20 m thick are also common. These are composed of two or more fining-upward or ungraded sandstones separated by major scour surfaces, or coarsening-upward deposits. The latter consist of red shaly to massive siltstone grading up into interlaminated siltstone and sandstone or intraclastic conglomerate (Figure 23, Sections E to G; Figure 24, Sections D, E and F).

Fining-upward sandstones of lithofacies D consist typically of a basal scour overlain by intraclastic and pebbly sandstone or locally conglomerates that are in turn overlain by

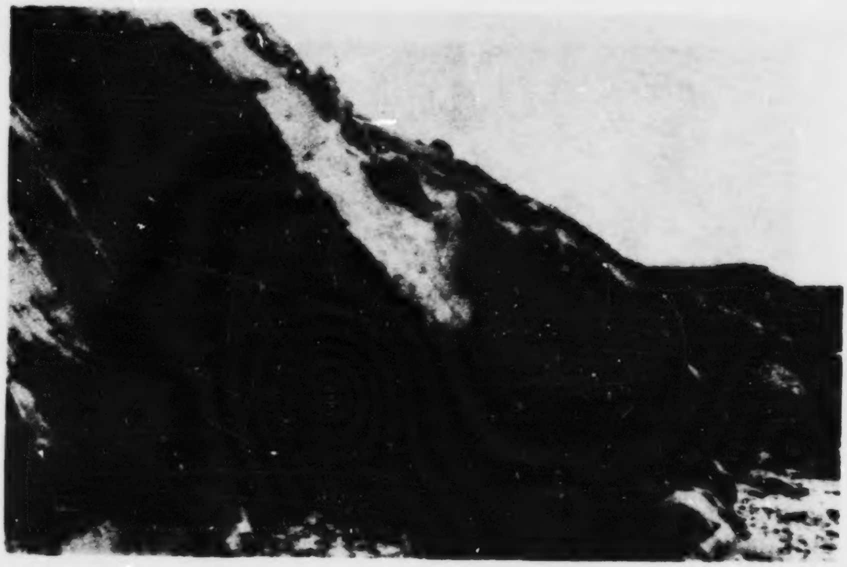


Plate 63: Multistory channel sandstones, lithofacies D, Jeffrey's Village Member, Robinsons River Formation, Jeffrey's coastal section. Scour bases are overlain by intraclast-rich sandstone and then crossbedded sandstone in the channel sandstones. A coarsely laminated red siltstone unit intervenes between two of the sandstones.

sandstones (Plate 63). Channel geometry was noted in some units in the Highlands Member.

Coarse to very coarse grained sandstones enclosing small diameter, red and green mudclasts, caliche pebbles, extrabasinal pebbles, and some coalified plant debris, form basal deposits 20 to 300 cm thick in the Jeffrey's Village and Highlands Members. They are generally absent or just a few centimetres thick in the Mollichignick Member. The deposits are typified by internal scours, crude to well defined planar stratification and some large, trough-crossbeds 20 to 40 cm and locally 1.5 to 2 m thick.

Above the basal deposits, graded, very coarse to medium or fine grained sandstones consist predominantly of large, trough-crossbeds. The crossbeds are mostly 10 to 40 cm thick but may reach 60 to 200 cm thick. The size of trough cross-stratification generally decreases upward, as does grain size. Units then pass up into, or intercalate with thinly stratified or laminated layers and wedges, that are 1 to 3 m thick, and carry current lineations. In some units (Figure 23, Section E; Figure 24, Section A, D and E), planar stratification dominates the sandstone units.

Some trough-crossbeds lie within channels or form hummocky ridges and depressions at the top of some sandstone units (Figure 24, Section E). An abandoned, siltstone-filled channel occurs 80 m above the base of the Highlands Member.

Ripple cross-lamination occurs near the top of units but is generally rare in all but the Mollichignick Member. Planar cross-stratification is also mostly restricted to sandstones in the Mollichignick Member. Here it occurs

Plate 64: Thick sandstone of lithofacies D with scours, pebble layers and large scale trough crossbedding which is deformed by large scale convolution. Fischells Brook, below JVL-2 limestone of the Jeffrey's Village Member.

near the top of units as small, multiple (5 to 15 cm thick) sets, or solitary, large (40 cm thick) sets composed of coarser pebbly detritus.

Large and small scale convolute deformation of both crossbeds and planar stratification is common and small scale sedimentary faults occur in planar stratified sandstones of the Highlands Member.

Not all fining-upward units are simple gradations of grain size and sedimentary structure up through the units. In one unit in the Mollichignick Member (Figure 25, Section B), there occurs a large channel, 200 cm at its deepest point and more than 19 m wide. It is scoured into previously deposited, equally thick, trough-crossbedded sandstone which overlies its own basal scour. The channel, which trends 160°-340°, was infilled laterally by three co-sets of southwestward dipping epsilon cross-stratification (Allen, 1963), each bounded by discontinuity surfaces. The final channel is filled by slightly asymmetric cross-stratification which mimics the final channel shape. The channel-fill and the earlier cross-stratified sandstones are both capped by trough-crossbedded and planar stratified sandstones beneath red siltstones.

Ungraded and coarsening-upward sandstones of lithofacies D form beds 1 to 6 m thick (Plate 64). The sandstones which are locally pebbly and intraclastic commonly occur in multistory sequences characterized by variable grain size and arrangement of sedimentary structure. In the Highlands Member for example, the sandstones are rich in intraclasts and red siltstone layers and lenses. Most sandstones begin with a scoured base, which in some instances has undercut and pried up wedges of underlying red siltstone. Large trough- and planar-crossbeds are common. Planar cross sets are up to 60 cm thick, but co-sets of smaller, planar crossbeds, 5 cm thick, are also common. Large trough-crossbeds, 40 to 130 cm thick, are abundant in the sandstones of the Highlands Member (Figure 24, Section F). Units that are planar stratified are regularly interlayered with those that are cross-stratified. Wavy laminated, sandy siltstones may divide up multistory sandstones, the siltstones grading up into overlying sandstones (Figure 23, Section F).

An ungraded sandstone unit of a different character was noted in the Jeffrey's Village Member (Figure 23, base of Section D), along Robinsons River. It consists of a 120 cm sequence of green-gray, intraclastic fine sandstone beds that are 20 to 50 cm thick, and are separated by 6 to 15 cm beds of red mudcracked siltstone. Above a basal scour, sandstone beds consist of 4 to 20 cm thick planar crossbeds and overlie planar to locally irregular internal scours. Red mudchips are concentrated on lower foresets and above the scours.

Coarsening-upward sandstones are rare except in the Mollichignick Member (Figure 25, Section C), where planar crossbedded, pebbly, very coarse grained sandstones overlie trough-crossbedded and planar stratified, medium grained sandstones.

Interpretation of lithofacies D: The sandstones of lithofacies D are interpreted as deposits of river channels.

The fining-upward sequences of the Jeffrey's Village, Highlands and Mollichignick Members are comparable to classical fining-upward sequences of meandering river channels (Allen, 1964a, 1965a, 1970a; Visher, 1972). They are the response of sedimentation to active migration of a meandering river channel and lateral accretion of a point bar on the inner bank of the meander bend. Gradual upward change of grain size and sedimentary structure in an ideal cycle occurs as flow conditions vary during the flood cycle and water depth becomes shallower over the point bar.

The pebbly and intraclastic coarse sandstones that lie upon the basal scour were laid down as lag deposits in the deepest part of the channel during the high stages of river flood. The deposits accumulated in scour pools (Leeder, 1973a) and by lateral accretion along channel thalweg (Allen, 1964a). Large crossbeds formed within megaripples at the base of the point bar (Harms et. al., 1963; Harms and Fahnestock, 1965) or by a process of scour and fill (McGowen and Garner, 1970) along the channel floor.

Deposits of the point bar proper include crossbedded and planar stratified sandstones that overlie the basal lags. Such structured sands are common within modern sandy point bars (Harms et al., 1963; Harms and Fahnestock, 1965; Steinmetz, 1967; Shelton and Noble, 1974) and in sandstones interpreted to represent ancient point bars (Allen, 1964a, 1965a, 1965b, 1970a; Moody-Stuart, 1966; Allen and Friend, 1968; Leeder, 1973a). Trough-crossbeds were deposited by migrating megaripples in the upper part of the lower flow regime (Simons et al., 1965), whilst planar stratification with parting lineation was deposited in the upper flow regime (Simon et al., 1965; Harms, 1975). Laterally extensive, thick deposits of planar stratification, such as occur in some of the facies units in the Highlands Member, have been noted in other ancient channel deposits like the Tugford cyclothem (Allen, 1964b). Such stratification is also documented at higher levels of the inside of modern sandy point bars (Harms et al., 1963; Harms and Fahnestock, 1965) and is extensively developed in a point bar of a low sinuosity reach of the Cimarron River (Shelton and Noble, 1974). Although thick planar stratification is also common in flash-flood-generated sandy crevasse-splays

(McKee et al., 1967; Tunbridge, 1981a), a meandering channel environment is suggested for this lithofacies because of the basal scours, locally with channel shapes, and their overlying lag deposits.

Ungraded and coarsening-upward sandstones that occur in the Mollichignick Member deviate from the classical fining-upward sequences of Allen (1965a). However, they are still interpreted as deposits of meandering river channels because of the thick siltstones with which they are associated. Jackson (1978) recently showed that deposits of meandering rivers have a wide spectrum of characteristics that may produce sequences deviating from those of the classical meander cycle. Sandstone sequences in the Mollichignick Member are dominated by trough-crossbedding, but include near the top of some sequences sets of planar cross-stratification which may be composed of pebbly sandstones. The sequences closely resemble overall vertical profiles of coarse grained point bars of meandering rivers (McGowen and Garner, 1970; Jackson, 1975, 1976). Planar crossbeds at the tops of these profiles developed in chute (McGowen and Garner, 1970) or scroll bars (Jackson, 1976) associated with chutes that traversed the top of the point bars during flood stage.

Braided stream deposits are probably represented by the ungraded or coarsening-upward, pebbly and intraclastic sandstones of both the Jeffrey's Village and Highlands Members. Abundant red siltstone layers and plugs in the succession suggest ephemeral or fluctuating flow typical of rapidly switching braided stream channels. Frequent reworking of both the sandstones and the adjacent flood plain deposits is indicated by scours, caliche pebbles and mudclasts, as well as the partial erosion of silt plugs (Allen, 1965a; Miall, 1977).

There is a close association in the Fischells Brook section (Figure 20) of these braided stream deposits with some marine carbonate and shale units of the upper part of the Jeffrey's Village Member. This suggests that some of the braided rivers discharged into shallow inland seas after traversing relatively narrow flood plains. Caliche layers immediately beneath and capping some of the channel sandstones are evidence of breaks in sedimentation.

(E) PEBBLY ARKOSIC SANDSTONE AND MUDDY SANDSTONE LITHOFACIES

Description of lithofacies E: Lithofacies E is developed near the margins of the subbasin, particularly along the Long Range fault where it forms at least three important sequences. These include (1) the Brow Pond lentil (Fong, 1976a,b) in the northeast corner of the subbasin near Steel Mountain, (2) a basin-fill sequence (Heward, 1978a) forming about 1300 m of the Mollichignick Member in the hills between the North and South Branches of the Grand Codroy River, and (3) a megasequence at least 344 m thick in the Overfall Brook Member (Figure 22). Other thick sequences of the facies are probably present to the southeast of the Barachois synclinorium in rocks laterally equivalent to the Highlands and possibly the Mollichignick Members.

Away from the basin margins, argillaceous and coarse arkosic detritus form single beds and sequences, 1 to 30 m thick. These occur in floodplain and lacustrine deposits of the Mollichignick Member in the Codroy lowlands and in floodplain and playa-flat deposits of the Jeffrey's Village and Highland Members, in the northern and eastern parts of the St. George's Bay lowlands. The facies forms a major element in a 2000 m drill hole that penetrates gently dipping strata of the Highlands Member near St. Teresa (Amax Exploration, 1976).

Plate 65: Conglomerate with crude stratification that cuts into crudely stratified, pebbly sandstone. Jeffrey's Village Member, Robinsons River Formation, Flat Bay section.

Lithofacies E is composed of white, pink and red, clean arkose and brown-red or gray argillaceous sandstone. The sandstones as a whole are coarse and very coarse grained, poorly sorted and submature (Folk, 1968), and are commonly pebbly or gritty. Conglomerate and some red siltstone are also present. The gray beds are commonly associated with lacustrine deposits of lithofacies H and I in the Mollichignick Member.

Basal scours cut into underlying finer lithofacies and major scours are common within thicker sequences of lithofacies E. Seven types of sedimentary structure have been found above the basal scours. They are (i) massive beds, (ii) crude to well developed planar stratification, (iii) planar cross-stratification, (iv) trough cross-stratification, (v) thin planar stratification and lamination (vi) small scale crossbedding and cross-lamination, and (vii) massive siltstone.

Massive beds are generally rare except in the Flat Bay section of the Jeffrey's Village Member, where they are composed of pebbly grits and conglomerates. The conglomerates, which are similar to facies Gm of Miall (1977) and Rust (1978), are clast- to matrix-supported (Walker, 1975a), and locally contain large intraclasts derived from associated lithofacies. Most of the beds occur immediately above or close to basal erosion surfaces.

Crude to well developed planar stratification occurs in deposits, up to 8 m thick, that are composed of clean or muddy, pebbly sandstones and grits (Plate 65), or rarely of conglomerate. The structure is most commonly developed close to basal erosion surfaces and is poorly to well defined by broad, shallow scours or by undulose layers, 1 to 4 cm thick; the latter are formed by lenticular segregations of coarser particles. The bed type resembles the horizontally bedded versions of facies Gm (Miall, 1977; Rust, 1978).

Planar cross-stratification occurs in sandstones, grits and conglomerates (facies Sp and Gp, Miall, 1977; Rust, 1978), generally above the planar stratified gravel deposits (Figure 25; Figure 23, Section I).

The crossbeds occur as solitary or multistory sets in sequences 1 to 3 m thick. Most sets are several metres in length and 15 to 40 cm thick, although locally the thickness may reach 110 cm. Straight to curved, graded, 2 - 4 cm thick foreset strata with dips up to 30° overlie sharp, flat scoured bases.

Varying sizes of trough cross-stratification are common in pebbly sandstones and grits (facies St, Miall, 1977; Rust, 1978) (Plates 66 and 67). The sets are solitary or in nested co-sets and occur mostly near the tops of sequences. The sets measure 40 to 100 cm wide, 10 to 20 cm thick, and one to several metres in length.

Thin planar stratification and lamination is uncommon, but where it does occur it is generally near the tops of sequences (Plate 67). It is preserved mostly in reddish brown, fine to medium grained sandstones that are commonly micaceous and argillaceous and form beds 10 to 50 cm thick. The flat, planar stratification (facies Sn of Miall, 1977; Rust, 1978) generally overlies flat surfaces that truncate earlier structures. Parting lineations were not observed.

Small scale crossbedding and cross-lamination (facies Sr and Fe of Miall, 1977; Rust, 1978) occur in fine red sandstones that are interbedded with red siltstones and with fine gray beds of lithofacies H and J. The sandstone beds are 10 to 25 cm thick, and are composed of single and multiple sets of small scale crossbeds. Rib-and-furrow structure and type A climbing ripple-drift (Jopling and Walker, 1968) also occur. Segregation of coarser grained material into laminae locally reveal horizontal to irregular thin stratification.

Structureless beds of siltstone (facies Fm, Rust, 1978) form beds 10 to 25 cm thick which may contain plant rootlets and mudcracks.

Friable, poorly cemented, clean arkoses are common in the Overfall Brook Member and in the Brow Pond lentil. Units of pebbly sandstone up to 20 m thick are common in the Overfall Brook Member (Figure 22) where they have massive bedding, crude to well developed planar stratification, and planar and trough cross-stratification. Finer grained interbeds up to 4 m thick also occur in the member and these either consist of structureless siltstone or else contain small scale current structures. Pebbles rarely exceed 20% of sandstones and no clear coarsening-upward trends in pebble abundance or size are evident in the Overfall Brook Member. Pebbles in the member consist of crystalline rocks that may have been derived from southeast of the Long Range Fault (Table 8).

Brown-red, argillaceous sandstones, pebbly sandstones and conglomerates typify the marginal basin-fill sequences of the Mollichignick Member. Similiar argillaceous lithologies occur intercalated in the Mollichignick type section which represents the basinward succession in the member. The marginal basin-fill sequence is typified by massive to crude stratification with lesser amounts of crossbedding. Lithofacies E beds and units in the type section of the Mollichignick Member, however, have a greater variety of sedimentary structures. These include lenticular bedding, massive bedding, crude flat bedding, planar- and trough-crossbedding, scour and fill structures and horizontal lamination. Bar-shaped, crossbedded pebbly sandstone deposits (Plate 68) also occur. Pebbles in

Plate 66: Large trough crossbedding in arkosic sandstones of the Overfall Brook Member, Robinsons River Formation, east bank of Grand Codroy River, north of Overfall Brook.

Plate 67: Trough crossbedding between planar thin stratification in red, muddy sandstones of the Overfall Brook Member, Robinsons River Formation, at mouth of Overfall Brook.

Plate 68: Bar-shaped deposit of crossbedded gritty sandstone, associated with pebbly sandstones. Note large pebbles lying at the base of the stoss side of the bar and stratification draped over the bar. Mollichignick Member, Robinsons River Formation, Grand Codroy River.

lithofacies E units of the type section can reach diameters of 20 cm, as for example in conglomerate outcrops in the bank of the Grand Codroy River, near Limestone Brook, and in the river bed of the South Branch River east of the Trans Canada Highway. Most pebbles, however, are 1 to 5 cm in diameter and consist of metamorphic and granitic rock types such as outcrop today southeast of the Long Range fault (Table 8).

The lithofacies in the Flat Bay section of the Jeffrey's Village Member is composed of conglomerates, pebbly sandstones and sandstones. Beds 60 to 500 cm thick, many cemented by caliche, occur in the lower 200 m of the section. They are interspersed in red shaly siltstones (lithofacies K). In the upper 230 m of the section, the lithofacies comprises sequences 20 to 45 m thick, separated by covered intervals that appear to hide red siltstones. Scours, massive bedding and abundant current bedding typify the lithofacies in the Flat Bay section. Two major scour surfaces occur in the upper 230 m of the section. Both surfaces truncate underlying beds and separate changes of strike and dip in beds above and below the scours.

The size of pebbles decreases upward in the Flat Bay section. Pebbles, 10 to 15 cm in diameter at the base of the upper sequence, decrease in size to 1 to 3 cm near the top of the section. Pebble composition suggests at least two sources. From the base of the Flat Bay section to 30 m above the base of the upper 230 m thick sequence, the pebbles consist of Cambro-Ordovician carbonates, quartzites, and ultramafics with minor granite and gneiss (Table 8, FB-1). Above the 30 m mark, Cambro-Ordovician carbonates and quartzites are absent. Instead, there is a second pebble assemblage (Table 8, FB-2 and FB-3) which is characterized by schist and phyllite, similar to rocks of the Fleur de Lys Supergroup, and by red and brown, silicic volcanics and granite resembling rocks of the Topsails Igneous Complex (Kean, personal communication, 1980).

TABLE 8: Pebble lithologies recorded in members of Robinsons River Formation

Jeffrey's Village Member

White quartz
White and pink quartzite
Red aphanitic rhyolite
Red porphyritic rhyolite
Ignimbrite
Black chert
Red jasper
Green amphibolite gneiss
Intraclasts of silt

from near Crabbes Head

FB-1
White and black quartzite
Red sandstone (Camb)
Foliated quartzite
Dolostone
Gray limestone (some mottled)
Chert
Red and gray granite
Granite gneiss
Quartz-mica schist
Green phyllite
Gabbro and ultramafic

FB-2
White quartz
White granite-gneiss
Pink foliated granite
Coarse, quartz-feldspar granite
Pink feldspar
Green quartzitic phyllite
Chlorite schist
Gray sandstone

FB-3
White quartz
Quartz-mica schist
Chlorite schist
Gray and green sandstone
Pink granite
Granite gneiss
Pink feldspar
Brecciated granite
Brown, aphanitic silicic volcanic
Brown and gray, quartzo-feldspathic porphyry and crystal tuff
Pink and yellow, spherulitic rhyolite
Red, pink and yellow, welded tuff and ignimbrite

from Flat Bay coastal section

Highlands Member

White quartz
White and pink quartzite
Red aphanitic rhyolite
Brown porphyritic rhyolite
Banded rhyolite
Black chert
Gneiss
Intraclasts of silt and caliche

from shore, north of Highlands River

Mollichignick Member

White quartz
Red mica granite
White muscovite granite
Red silicic volcanic
Porphyritic rhyolite
Granite gneiss
Green chloritic schist
Green gabbro
Green-gray diabase
Black chert

from north of South Branch River

White and rosy quartz
Pink granite
Quartz-mica-feldspar pegmatite
Muscovite-biotite-schist
Green argillite
Green chlorite schist and phyllite
Mylonitic quartz
Black lineated biotite schist
White quartz-muscovite schist
Quartz-amphibolite breccia

from 5 conglomerate beds along Grand Codroy River between South Branch and the Overfall Brook

Overfall Brook Member

White quartz
Mylonitized quartz
Shattered quartz
Quartz-mica schist
Dark gray phyllite
Pink feldspar
Red granite
Porphyritic rhyolite
Gneiss
Green fine ultramafic

from Overfall Brook type section

White and rosy quartz
Pink feldspar
Pink granite
Green, amphibolite gneiss
Black biotite schist
Green chlorite schist

from Mollichignick Brook

White quartz
Quartz-feldspar granite
Pink feldspar
Black amphibolite
Quartz-muscovite pegmatite
White schistose quartz
Black phyllite

Basal beds, Grand Codroy River north of Overfall Brook

Interpretation of lithofacies E: The pebbly and muddy coarse sandstones of lithofacies E possess characteristics of braided stream deposits, recently summarized by Miall (1977) and Rust (1978). The facies accumulated on alluvial fans along the subbasin margin, in fan lobes that prograded onto the adjacent flood plain, and in braided streams that crossed the flood plain.

Variable internal structure in gravels and sands of the facies suggests that they were deposited on bars, and by megaripples in stream channels. The massive pebble beds with crude planar stratification were probably deposited in channels as longitudinal bars (McDonald and Banerjee 1971; Rust 1972; Eynon and Walker, 1974; Smith, 1974; Gustavson, 1974; Miall, 1977; Rust, 1978) as floodwaters lost their ability to carry bed load (Miall, 1977). Deposition would have occurred in scour pools (Smith, 1974), at obstructions in channels or where the channels widened.

Sheet-like deposits of horizontally and crudely bedded gravels and sands resemble sheetflood deposits of modern and ancient alluvial fans (Bluck, 1967; Bull, 1972; Collinson, 1972; Steel, 1974). Such sheetflood deposits form when coarse bed load leaves the confines of fan channels during floods to spread out over wide areas of an active fan lobe (Bull, 1972; Heward, 1978a). Some massive, matrix-supported conglomerates and crudely stratified, muddy, pebbly sandstones were probably deposited by debris flows (Walker, 1975a; Miall, 1977; Rust, 1978).

Planar cross-stratification was most likely formed by migrating sand waves (Harms, 1975) and transverse (Smith, N.D., 1970, 1971, 1974), linguoid (Collinson, 1970a) or cross-channel bars (Cant, 1978). These bars are common in both sandy and gravelly braided systems. They propagate from slip faces of other bars (Rust, 1972; Smith, 1974) or are superimposed upon earlier bar deposits (Miall, 1977; Cant, 1978). The crossbeds were deposited under lower flow regime conditions (Harms, 1975) during the later stages of flood cycles.

Large scale, trough cross-stratification was formed in channels by migrating megaripples (Collinson, 1970a; Cant, 1978; Cant and Walker, 1978). Smaller, trough-crossbeds intercalated with horizontal and thinly stratified sandstones were probably deposited in shallow water as smaller megaripples migrated over the tops of large bars. Modification of these bar tops during late, waning flood stage also produced scours that were filled by trough-crossbeds.

The fine red sandstones and siltstones of lithofacies E are associated with fine gray beds (lithofacies D) and have small scale current structures. They were, therefore, deposited in a quieter depositional setting than the coarser deposits of the facies. Small scale trough-crossbedding and ripple cross-lamination was formed by migrating ripples (Harms, 1975) during the last stages of flood or at low water in the braided stream system (Miall, 1977; Cant and Walker, 1978). Fine deposits also occur in pools within abandoned or inactive channels in braided stream systems and in abandoned lobes of alluvial fans (Doeglas 1962; Williams and Rust, 1969; Heward, 1978a). Vegetation locally stabilized these deposits and desiccation cracks formed when pools dried up.

Lithofacies E dominates mega-sequences and also some basin-fill sequences (Heward, 1978a) in the Mollichignick Member near the Long Range fault. These deposits are interpreted to have been laid down by alluvial fans that were built northwest of the paleo-Long Range Highlands. The apparent infrequency of debris flows (Hooke, 1967) or coarse stream gravels (Boothroyd, 1972; Boothroyd and Ashley, 1975) suggests that the observed deposits were not the most proximal deposits of the fans. Thus the mountain front may have receded east of the present day Long Range fault as a result of erosion or perhaps movement on basin-margin faults (Bull, 1972; Heward, 1978a).

The marked textural difference between the fan deposits of the Mollichignick Member and the deposits of the Overfall Brook Member may reflect a climatic change from semiarid to more humid conditions. Evidence for the change is: 1) the presence of thick caliche beds in the Mollichignick Member, but their absence in the Overfall Brook Member (Giles et al., 1966; Reeves, 1970; Steel, 1973; Allen, 1974; Leeder, 1975), and 2) the importance of clean sediment and abundant current structures in the Overfall Brook fan, indicating an active braided fluvial system typical of humid fans (McGowen and Groat, 1971; Reineck and Singh, 1975; Collinson, 1978a). It is important to note, however, that well worked arkoses may occur in semiarid areas where streams drain a granitic terrane (Shepard, 1975).

Away from the subbasin margins, individual beds or sequences of the lithofacies are intercalated with floodplain, playa flat and lacustrine lithofacies. Here they are interpreted as deposits of sandy and gravelly braided streams. Where the facies forms the upper part of coarsening-upward sequences that include floodplain siltstones (lithofacies A) and stratified sandstones (lithofacies C), it was probably part of a prograding alluvial-fan lobe (Leeder, 1973a; Hardie et al., 1978; Heward, 1978b). The coarsening upward may reflect increased rainfall or tectonic activity (Bull, 1972; Heward, 1978a). Both phenomena may have caused the fan-head channel to entrench so that coarse detritus bypassed the fan apex and was deposited lower on the fan or on the adjacent flood plain.

Conglomerates and pebbly sandstones in the Flat Bay section of the Jeffrey's Village Member are associated in the lower part with playa flat shaly siltstone and in the upper part with alluvial(?) plain siltstones. The lower 200 m of the section were deposited by ephemeral braided streams carrying gravels onto the inner edge of a playa flat; calcretes then developed within, and cemented, the stream gravels. Pebble lithologies in the lower 230 m of the section suggest derivation from the Humber Arm Allochthon highlands to the north. Their absence higher in the section, and replacement by metasedimentary and silicic volcanic pebbles, indicates that the younger series of fans was built out into the basin from the northeast and east. Major scour surfaces separating beds of differing strike and dip suggest that overlap of two or more fans probably occurred. Lack of caliche and predominance of crossbeds in the upper sequence may reflect more active fluvial sedimentation (Leeder, 1975).

(F) CALICHE LIMESTONE LITHOFACIES

Description of lithofacies F: Three types of limestone occur in this lithofacies. They are (1) nodular caliche, (2) siltstone and sandstone beds cemented by carbonate and (3) thick beds of pale gray limestone. The lithofacies is present in all but the Overfall Brook Member and the Brow Pond lentil.

Caliche concretions are most common in lithofacies A siltstones, where they vary from pea-shape and-size to larger, rather elongate, flat to very irregularly shaped nodules. In the Highlands Member, the concretions are also associated with vertical cylindroids, (Hubert et al., 1978).

The second type of caliche consists of thoroughly or incompletely cemented beds of other lithofacies (Plate 69). As

Plate 69; Two beds of caliche in red siltstones of the Mollichignick Member of the Robinsons River Formation, south of the mouth of Stephen's Brook, Grand Codroy River. Lower bed is cemented siltstone (cb), upper bed is relatively pure, clean limestone.

such, it includes color-mottled, pale gray to reddish gray, cemented siltstones and sandstones that form resistant rock ledges in red siltstones of the Jeffrey's Village (Figure 23, Section H), and Mollichignick Members (Figure 24, Section A and E). The calcareous siltstones typically contain small clots and nodules of almost pure carbonate, that are 0.5 to 1 cm in diameter, and they are crosscut by fractures cemented by calcite spar. Most internal structures have been destroyed. Cemented sandstone beds occur at the top of lithofacies D in the Mollichignick and Highlands Members. Lithofacies E conglomerates and pebbly sandstones are cemented in the lower 55 m of the Flat Bay section of the Jeffrey's Village Member (Plate 70). Gradational, irregular and locally transgressive bases are typical of the cemented beds while tops are mostly hummocky and either sharp or gradational.

Pale, gray to purplish, microcrystalline limestone beds, 30 to 130 cm thick, form the third type of caliche, (Figure 23, see Sections F, G and H; Figure 24, Section E; and Figure 25, Sections A, B, C and F). The beds are internally massive, but near their tops they contain concretionary structures, 5 to 10 cm in diameter, that are associated with 0.5 to 1 cm pisolitic nodules, red siltstone partings and laminar structure (Plate 71). Stylolites may also occur. The bases and tops of the limestone beds are mostly sharp and knobby. Small caliche pipes occur in red siltstones beneath some of the thicker beds.

Although most caliches of this type are single beds, some units in the Highlands and Mollichignick Members consist of two or more beds with complex relationships between caliche and host rock. In the Highlands Member, one

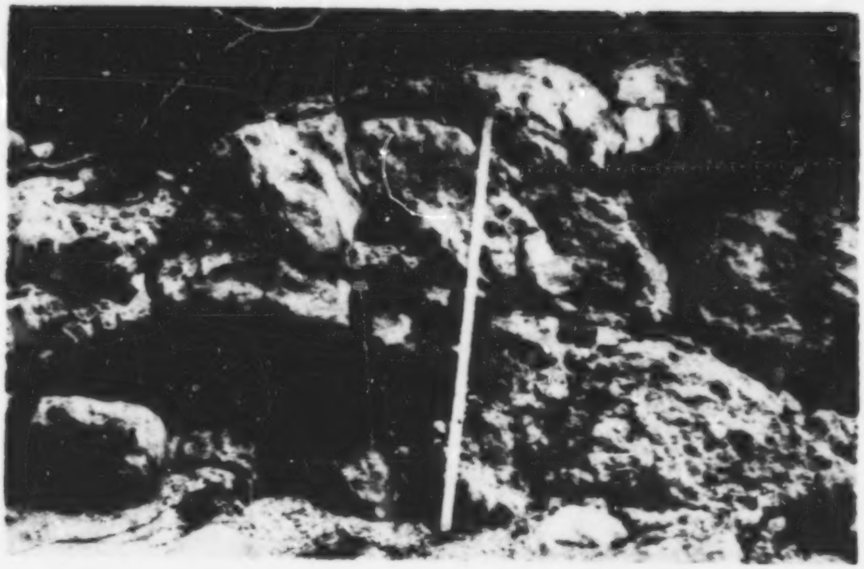


Plate 70: Caliche cementing a conglomerate bed in the lower part of the Flat Bay section of the Jeffrey's Village Member, Robinsons River Formation.

Plate 71: Thick nodular caliche with laminar top and remnants of red siltstone in Mollichignick Member, Robinsons River Formation; tributary entering the north side of South Branch River.

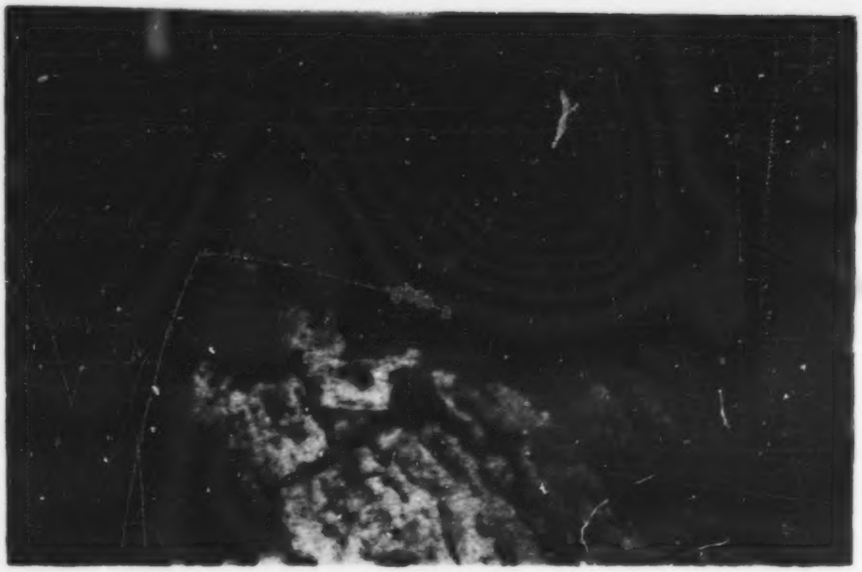


Plate 72: Intraformational conglomerate lithofacies G, Highlands Member of Robinsons River Formation in a channel (arrow) cutting through red siltstone that contains cylindroid caliche of plate 73. The channel eroded to the top of the underlying red sandstone unit. Thick, massive caliche with blocky fracture capped all lithologies.

Plate 73: Vertical cylindroids or pipes, some with hollow centres (arrow) projecting down into red siltstones within the Highlands Member type section. Note basin-shaped deposits of caliche above hammer. A 15 cm siltstone layer separates the cylindroid caliche from overlying massive caliche bed shown in plate 72.

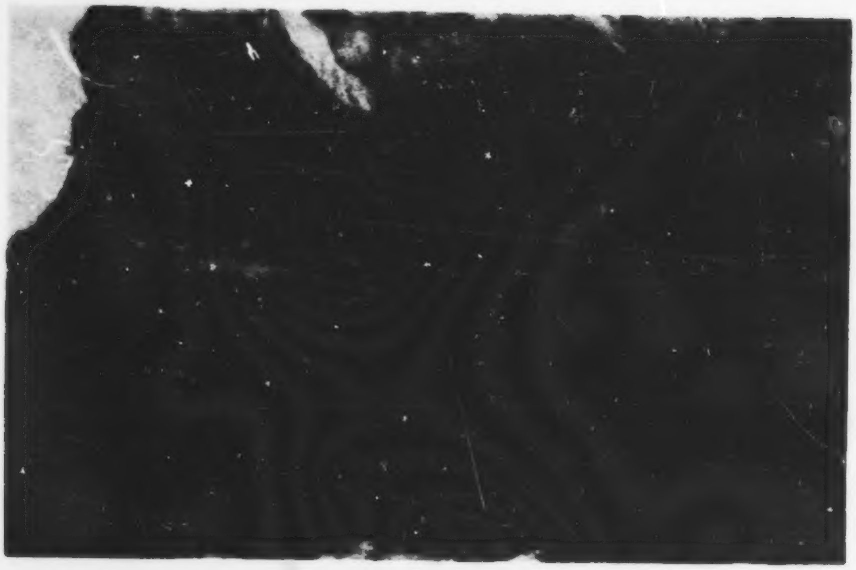


Plate 74: Purple-gray and red caliche bed splitting a pebbly sandstone bed in two. Note depression filled by caliche at top of metre stick and large block of pebbly sandstone enclosed in the caliche immediately above arrow. Jeffrey's Village Member, Robinsons River Formation, Flat Bay section.

lithofacies A siltstone unit (Figure 24, Section E), contains at least three caliche horizons (Plate 72). The first occurs in a deep scour at the top of a lithofacies D sandstone and is covered by 220 cm of red siltstone. The caliche and siltstone are crosscut by a deep channel that is filled by intraformational conglomerate (lithofacies G) and the channel-fill and siltstone are capped by 55 cm of caliche. The latter appears to be one bed above the channel, but when traced laterally outside the channel and above the siltstone, it splits into two beds, 26 cm and 20 cm thick, separated by 10 to 15 cm of siltstone. The lower 20 cm caliche bed has a sharp, but uneven contact with the interbedded siltstone. Obliquely dipping caliche dikes and cylindroids 5 to 15 cm in diameter (Plate 73) extend downward below the bed which also contains bowl-shaped deposits of calcrete. The latter are 45 cm in diameter and 20 cm deep, with downward-protruding pipes at the bases. The dikes and cylindroids penetrate the siltstone for up to 100 cm and many have hollow tubes, 1 to 2 cm in diameter, passing through their centres. The upper caliche bed has typical knobby concretionary texture (Plate 72).

In the Jeffrey's Village Member at Flat Bay, some caliche units in the red shaly siltstone have a columnar structure similar to that described from Carboniferous calcretes in Kentucky (Wall et al., 1975). In the same section, a type 3 caliche limestone, 45 cm thick, lies within a conglomerate bed 118 cm thick (Figure 23, Section H). The caliche has a sharp base but a diffuse upper contact with the conglomerate. At one place in the bed, the caliche thickens (Plate 74) and fills a depression in the underlying conglomerate. Immediately above the depression it encloses a large wedge of conglomerate that has dimensions similar to those of the depression.

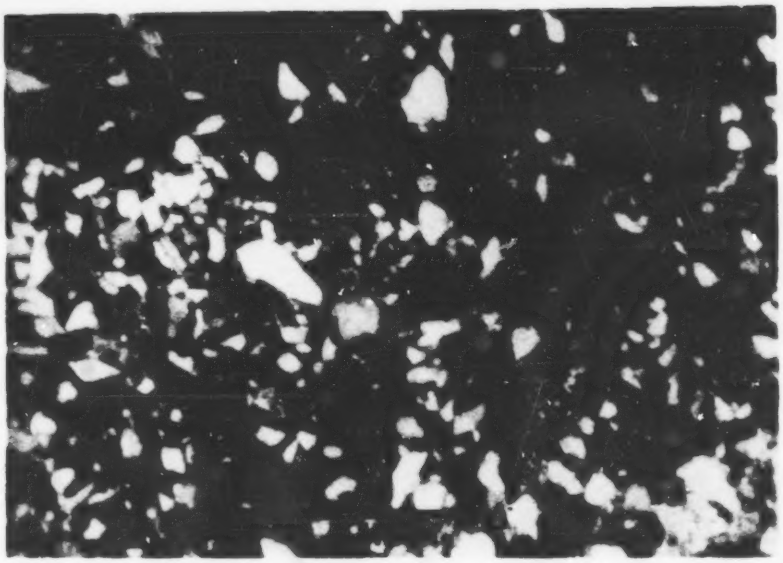


Plate 75: A photomicrograph of a cemented siltstone bed from the Mollichignick Member, showing the transition from calcareous siltstone to silty limestone at the margin of a pure carbonate nodule.

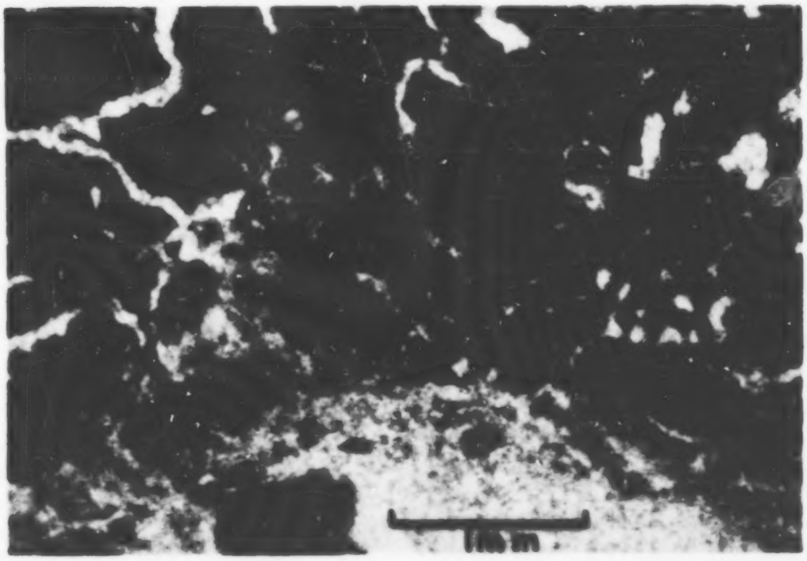


Plate 76: Photomicrograph of an old caliche, Mollichignick Member. It is composed of micronodules of dark micrite within lighter colored microspar. A shale parting is visible beneath the microspar. Dilation cracks surround and cut across the nodular micrite. They are now filled by microspar cement.

Plate 77: Bed of siliceous caliche in the Mollichignick Member, Robinsons River Formation, Grand Codroy River. Red to brown chert occurs within generally massive, gray limestone.

Petrographically, the cemented beds consist of clots of almost pure, microcrystalline carbonate which are surrounded by very fine, mottled, cloudy, sandy and silty microspar (Plate 75). The angular detrital grains, particularly those composed of quartz and feldspar, are corroded and many are intruded by calcite veinlets; mica flakes have been dismembered by spar precipitated between cleavage planes.

The more pure caliche consists of dense, brown, cryptocrystalline micrite and silty micrite with clear microspar in streaks, patches and pore fillings (Plate 76). Discontinuous partings of fine silt, kaolinite, sericite and fibrous calcite occur within the micrite. The micrite is also characterized by irregular to wormy microfractures, angular, curved and branching dilation cracks, and fenestral-type pores filled by microspar and coarser spar.

Silicification was observed in three caliche beds along the Grand Codroy River between Limestone and Overfall Brooks (Plate 77). The chert occurs as irregular masses and stringers in microcrystalline limestone. It is red in color and either cryptocrystalline or formed of fibrous, length-fast chalcedony. The chert lies within irregular areas of slightly coarser microspar that occur within the dense, brown to light brown, microcrystalline limestones. Vugs in the chert are lined by chalcedonic colloform layering and by coarser, fibrous, length-slow chalcedony. Remaining voids were filled by calcite, equigranular quartz or hematite. Hematite occurs along the margins of the chert grains and in clots surrounding irregular nuclei of colourless chert. The carbonate has not been tinted by the hematite.

Pink, dolomitic caliche layers, 5 to 15 cm thick form bounding deposits above and below thick lithofacies D sandstone sequences at Fischells Brook (Figure 23, Section H). Similar pink caliche lies immediately beneath the lower gypsum bed at Rattling Brook (Figure 31) and may correlate with the upper pink caliche of Section H (Figure 23).

Interpretation of lithofacies F: The carbonates of facies F resemble pedogenic caliche limestones that form in modern arid and semiarid areas (Gile et al., 1966; Reeves, 1970; Bull, 1972; Goudie, 1973; Lattman, 1973). Caliches are also well documented from ancient nonmarine strata (Steel, 1973; Allen, 1974; Leeder, 1975; Allen and Williams, 1979). They are known to develop within soils of alluvial plains, on alluvial terraces, along exposed ephemeral stream courses and on inactive areas of alluvial fans (Gile et al., 1966; Bull, 1972; Lattman, 1973; Allen, 1974). Since caliches usually take thousands of years to form and therefore only occur where sedimentation rates are low, they give some idea of these rates and of the behaviour of fluvial systems on floodplains.

The carbonates are precipitated in the 'K' horizon of soils (Gile et al., 1966). Carbonate provided to the sediment as wind-borne lime dust (Gile et al., 1966; Goudie, 1973) is leached by downward-percolating rainwater and is precipitated in the subsurface when the soil waters evaporate during the dry season. Thickening of the 'K' horizon continues as carbonate is precipitated, with repeated wetting and drying of the sediment for hundreds or thousands of years. Consequently, caliche profiles change with time as carbonate buildup progresses (Table 1 of Gile et al., 1966; Leeder, 1975). Long-lived caliche formation occurs when permeability, allowing downward percolation of mineralized rain water, is maintained. Where permeability is reduced, the mature profile will be plugged by carbonate so that a laminar layer develops above the nodular caliche. Laminar layers generally indicate old deposits, but both Reeves (1970) and Lattman (1973) showed that the structure can also develop in younger deposits where original permeability is poor. The presence of "cylindroids" some with hollow tubular centres, in the thick caliche of the Highlands Members, suggests that in some instances, the caliche was precipitated on biogenic soils around extensive root systems (Hubert, 1977).

Four stages of caliche that include the three caliche types recorded in facies H are defined by Gile et al., 1966. Filaments and coated grains typical of Stage I were not found in the Robinsons River Formation, but nodular caliche similar to stage II (Gile et al., 1966) of young profiles (Reeves, 1970) is common; this requires 3000 to 7000 years to form (Leeder, 1975). Continuous beds and lumps of carbonate-cemented siltstones, sandstones and conglomerates with embryonic pure calcite nodules represent stage III (Gile et al., 1966), which is typical of early and later mature profiles (Reeves, 1970). This stage probably lasts 6000 to 10,000 years (Leeder, 1975). Thick nodular, massive, brecciated, laminar, locally pisolitic and cherty pure limestones represent stage IV (Gile et al., 1966). They are indicative of old caliche profiles (Reeves, 1970) which require more than 10,000 years to form (Leeder, 1975). Etching, dissolution and replacement of detrital sand grains by calcite is common and progresses with profile maturity (Steel, 1973).

Young profiles of small nodular caliche are common in flood plain siltstones, and levee and crevasse-splay deposits of all three host members. In the Jeffrey's Village Member, old profiles are not common but do occur in the Flat Bay section where they formed in both playa flat and gravelly braided stream deposits. A few mature and old caliches and dolomitic caliche beds also occur in the Fischells Brook section just above the Heatherton limestone. Here they are closely associated with floodplain and sandy braided stream deposits. This suggests that fluvial sedimentation of the redbeds immediately above the Fischells limestone was intermittent with long periods of nondeposition. Lack of all but small nodular caliche in the fine redbeds of the upper part of the Jeffrey's Village Member suggests increase in sedimentation rate with time (Leeder, 1975). Dolomitic caliche associated with both fluviatile deposits and marine beds may indicate that some caliches were affected by marine flooding or salt spray from a nearby marine shoreline (Scholle and Kinsman, 1974).

Young to mature caliche profiles in the Highlands Member are common, but old profiles are found only in the middle of the member. The scarcity of old profiles may in part reflect high sedimentation rates, but the abundance of caliche intraclasts in channel deposits also suggests extensive reworking of floodplain deposits by rivers.

Caliche limestones occur in both axial floodplain and marginal alluvial fan sequences in the Mollichignick Member. However, the floodplain sequences generally correspond to caliche-rich sections and the alluvial fan sequences to caliche-free sections. This distribution is apparently maintained when the succession is traced laterally toward the margins of the subbasin, which suggests a long term allocyclical control such as tectonic activity or climatic variation (Allen, 1974; Leeder, 1975). Caliche-free successions correspond to prolonged periods of high sedimentation, and the progradation of sandy and pebbly alluvial fans into the basin. Autocyclical controls, for instance the morphology of the alluvial plain, channel switching and river entrenchment (Allen, 1974; Allen and Williams, 1979), influenced the local caliche distribution within the caliche-rich sections. In these sections, carbonate cementation of the top beds of channel sandstones (Figure 25, Section B) may indicate rapid abandonment of river channels followed by extended depositional hiatuses. Old and siliceous caliches suggest major breaks in sedimentation lasting 10,000 years or more (Leeder, 1975). The presence of more than one caliche bed in a sequence may have resulted from the elevation of some areas of the floodplain (Allen, 1974), which then remained as zones of non-deposition except during major floods.

Lack of caliche in the Overfall Brook Member may reflect increased humidity so that higher sedimentation rates (Leeder, 1975) and increased mineral leaching (Reeves, 1970) prevented soil development and precipitation of carbonate.

(G) INTRAFORMATIONAL CONGLOMERATE LITHOFACIES

Description of lithofacies G: Intraformational conglomerates composed of caliche pebbles and mudclasts form discrete, channel-bound deposits within lithofacies A siltstones. The deposits are 14 to 387 cm thick in the Highlands Member but rarely thicker than 70 cm in the Mollichignick Member. They are brown, red and white in color and their bases are erosive into the host siltstones. Two types occur: the first lacks extrabasinal sand or pebbles, and the second is mixed with quartz sand and some white quartz pebbles. Channelling is present in both types (Figure 24, Sections E and F). One channel in the Highlands Member (Figure 24, Section E) was eroded into a 220 cm red siltstone unit and was later capped by caliche (Plate 72). The channel, 282 cm deep, is scoured irregularly and steeply through the siltstone and has eroded deeper where the siltstone fills an abandoned chute channel in the top of the underlying, fining-upward channel sandstone. Caliche pebbles, which are 1 to 2 cm in size, show little modification of their nodular shape and are set in a matrix of sand-size caliche fragments and mud chips. Crude stratification and crossbedding with lenticular sandy layers characterize the channel deposits, and large scale trough-crossbedding, 50 cm thick, occurs throughout the thickest deposit of this facies in the Highlands Member (Figure 24, Section F).

Interpretation of lithofacies G: The thick, channel-bound deposits form a minor lithofacies that resulted from peculiar processes on the flood plain. The predominance of caliche and mud clasts in the conglomerates and the rarity of extrabasinal detritus suggests that the depositing fluvial system originated within the basin, reworking floodplain alluvium and its contained pedogenic horizons. Where this fluvial system tapped an older channel sand, quartz sand and pebbles were also mixed into the deposits. Deep channelling suggests high energy events with the ability to erode and transport caliche pebbles. Little modification of original nodule shape by abrasion indicates generally short-lived events. The large crossbeds, 50 cm thick, probably formed in large megaripples (Williams, 1971; Karcz, 1972; Allen and Williams, 1979).

The evidence indicates that the lithofacies formed in response to high energy, short-lived floods which eroded channels in the floodplain sediments. They were generated on the flood plain and were independent of rivers entering the subbasin from outside its perimeter. Such deposits are capped by siltstone and caliche limestones because they formed locally and were rarely repeated in the same geographic locality. Catastrophic local superfloods which scour and flush out all available sediment are documented for small drainage basins of arid regions of the southwestern United States and semiarid areas of central Texas (Baker, 1977).

Similar deposits were recently described by Allen and Williams (1979) in the Siluro-Devonian redbeds of South Wales where conglomerates overlie thick caliche limestones. They interpreted the deposits as products of ephemeral, braided streams, generated on elevated interfluvial geomorphic surfaces between large, perennial meandering river systems.

(H) GRAY, CARBONACEOUS AND MICACEOUS MUDSTONE-SILTSTONE LITHOFACIES

Description of lithofacies H: Lithofacies H occurs in the Mollichignick and Overfall Brook Members. In the Mollichignick Member, it is between 0.5 and 6 m thick and consists of thin and flat bedded, intercalated dark to light gray mudstones and siltstones, containing lenses and beds of gray arkosic sandstone. The bedded mudstones and siltstones are locally deformed by sedimentary faults, slump folds and brecciation. The lenticular sandstones occur toward the top of the bedded lutites, and have eroded into them, enclosing fragments as large intraclasts. The lenticular deposits are then capped by trough-crossbedded, gritty and pebbly gray arkosic sandstones (lithofacies E) to form overall coarsening-upward sequences, 1 to 8.6 m thick (Figure 21; Figure 26, lower lacustrine sequence section B).

In the Overfall Brook Member, the lithofacies is slighty different, occurring in poorly exposed, recessive units 0.5 to 4 m thick. The units consist of 10 to 25 cm thick beds, of gray silty mudstones and muddy siltstones, very fine to fine grained sandstones that are gray to pinkish gray, and minor shales. Apart from their color, the sediments of this lithofacies are characterized by micas and carbonaceous plant fragments. Typical sedimentary structures in the sandstones are basal scours, cross-bedding, lamination and cross-lamination, convolution of ripple-drift, and small pockets of grit; plant rootlets have disrupted the laminations and ripple-drift. The shales, which may occur as thin lenses or partings between or in the sandstone beds, have mudcracks, whilst the mudstones are mostly structureless.

Interpretation of lithofacies H: The gray color, abundant plant debris, high mica content and fine grain size contrast with the oxidized and coarser deposits with which the lithofacies is mostly associated. In the Mollichignick Member, the flat, thinly interbedded gray mudstones and siltstones were probably deposited in a quiet, shallow lacustrine setting. The association of the lutites with gray sandstones in coarsening-upward sequences suggests the lake bottom sediments were buried by prograding sandy deltas.

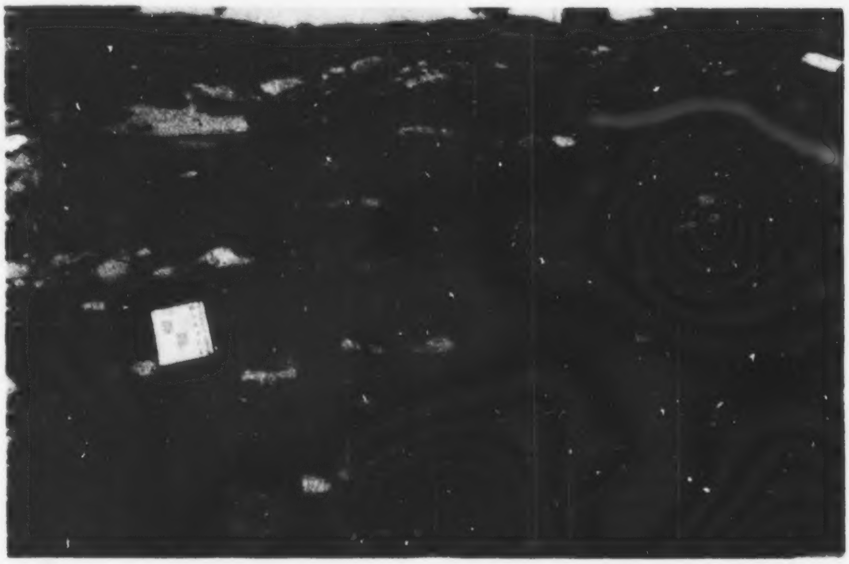


Plate 78: Interbedded calcareous mudstones and carbonates of lithofacies I, Mollichignick Member. Locality as in Section A, Figure 26, upper lacustrine sequence, North Branch River.

Plate 79: Small concretionary carbonate in calcareous mudstones of lithofacies I, Mollichignick Member. Locality as in Section A, figure 26, upper lacustrine sequence.

Small lakes were also the probable depositional environment of the lithofacies within the Overfall Brook Member. Current structures typical of low energy flow conditions (Harms, 1975), abundance of micas, plant trash and shale interbeds suggest quiet restricted conditions in which fines were readily trapped to the exclusion of the coarse debris. The lakes may have formed in abandoned braid channels upon the alluvial fan (cf. Meckel, 1975).

(I) INTERCALATED CALCAREOUS MUDSTONE - CARBONATE - MICACEOUS SANDSTONE LITHOFACIES

Description of lithofacies I: This lithofacies occurs exclusively in the Mollichignick Member where it forms sequences up to 50 m thick in the lower half of the member (Figure 26, Section A, upper lacustrine sequence Section B, and Section C). The facies consists of three rock types: drab, gray calcareous mudstones; nodular, concretionary and bedded dark gray to black carbonates; and gray, very fine to fine grained, micaceous sandstones (Plates 78 to 81).

The three lithologies are arranged in two different associations. In the thickest unit (Figure 26, Section A), the first association begins and finishes with micaceous sandstones that sandwich a thick middle development of mudstone and carbonate with some thin sandstone beds. In the second association (Figure 26, Section B, and probably partly by Section C) the rocks form coarsening-upward sequences, 2 to 6 m thick, beginning with intercalated mudstone and carbonate and completed by sandstone.

The drab, gray calcareous mudstones consist mostly of massive beds, 10 to 60 cm thick, with some thin layers that are laminated or fissile. The mudstones which are interbedded with carbonate beds, 5 to 10 cm thick (Plate 78) are petroliferous, carbonaceous, and locally contain ostracod fragments and small dolomite nodules. Large burrows are common in some beds, whilst in others there are fine tubular burrows, that are preserved by calcite spar and are about 1 mm in diameter. Some mudstone beds are brecciated and the fine fractures filled by mudstone; irregular spar-filled fractures cut through both carbonate and mudstone.

The carbonates consist of black to dark gray, bituminous limestones and bedded and concretionary dolomitic limestones and dolomites. The bedded carbonates, which are cryptocrystalline and contain ostracods, are structureless except for some fine bioturbation and poorly developed lamination. The concretionary dolomites are composed of small nodules (Plate 79) and angular, platy, brecciated dolomite fragments, set in a carbonate or mudstone matrix. The nodules are structureless but the fragments show a faint lamination and very fine spidery network of tubules. Narrow spar-filled dilation fractures occur around nodules (Plate 80). The fractures curve around the particles and short splays branch off them at intervals.

Dark to light gray, micaceous, very fine to medium grained sandstones, rich in plant remains, occur in sequences 1 to 5 m thick. Sandstone beds, 5 to 45 cm thick, are interbedded with gray shale beds 10 to 30 cm thick. Erosional bases and planar and undulose lamination (Plate 81) characterize the sandstones. They also have some small, shallow crossbeds, ripple cross-lamination, symmetrical convolution, and large burrows. The flat stratification in the deposits of section C, Figure 26, is defined by grain size and sorting of micas from quartz and feldspar. Laminations are inversely graded when the sandstones themselves coarsen upward but normally graded when the sandstones fine upward. Trough-crossbedded, intraclastic, fine to medium grained sandstones up to 2 m thick lie with erosive bases upon the finer micaceous sandstones or mudstones of the facies. The crossbeds, which are locally convoluted, are 5 to 15 cm thick and up to 1 m in length.

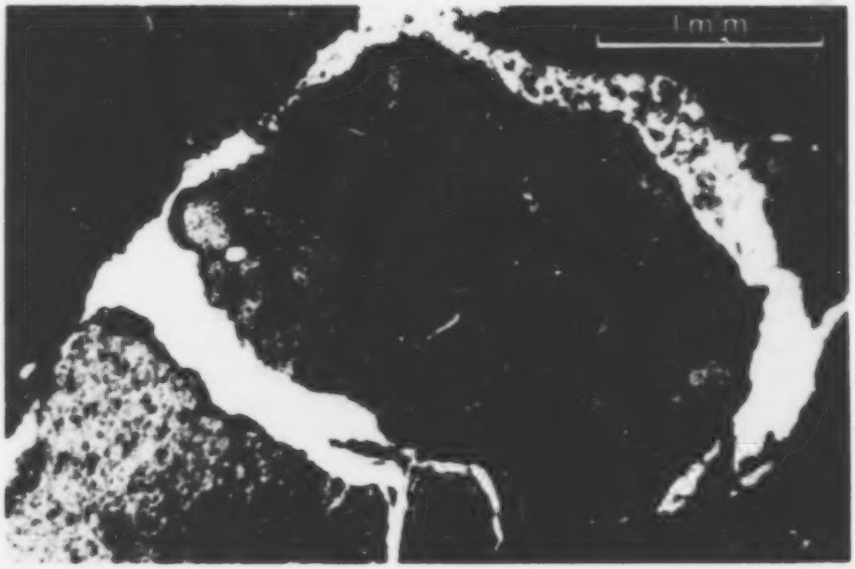


Plate 80: Photomicrograph of nodular carbonate from paludal mudstones that form part of section A of Figure 26. The carbonate is cut by curved dilation cracks filled by clear spar. Finer cracks splay off the main fracture similar to those described for paludal muds and carbonates by Freytot (1973).

Plate 81: Planar, thinly stratified, micaceous, gray, very fine sandstones with local convolution and some crossbeds, lithofacies I, Mollichignick Member, Grand Codroy River, 1 km north of the village of South Branch (section A, figure 26).

Interpretation of lithofacies I: The sediments of lithofacies I were deposited in quiet, perennial lakes and are interpreted as lake-centre muds and carbonates, paludal muds and carbonates, and marginal sands.

General lack of dessication features in the fine lacustrine deposits suggests the lakes were long-lived features. Fine tubular burrows may indicate that worm colonies flourished in the lakes (Reineck and Singh, 1975). Larger burrows were possibly produced by roots of aquatic plants which may have been abundant since both mudstones and limestones are petroliferous.

Some of the calcareous mudstones contain concretionary carbonate, and brecciation textures typical of paludal carbonates. They indicate that postdepositional, pedogenic and subaerial diagenetic processes affected the exposed lacustrine deposits (Freytot, 1973). Fine mottling in the laminated breccia fragments may represent calcified rootlets (Klappa, 1979), and lamination and abundant spar-filled fractures resemble the laminar structure and dilation cracks of caliche (Steel, 1973). The curved branching fractures are like structures described by Freytot (1973) from pedogenically altered lake and marsh mudstones and limestones. This suggests the nodules may have grown in zones of water-table oscillation where carbonate was concentrated. Fractures formed as the sediments were repeatedly moistened and dried out.

Algal mats, with fine lamination rich in fenestral porosity, flourished in sheltered shoreline settings around the lake or in shallow pools in the marsh environment.

Fine micaceous sandy detritus was supplied to the margins of the lakes by shallow streams and rivers. The sandstones were laid down as broad sheets during floods and are overlain by shales that were deposited from suspension between flood events. Many coarsening-upward sequences were formed as deltas built out into the lake. Coarser grained, crossbedded sandstones probably represent channel deposits. Planar, thinly stratified sandstones, again in coarsening-upward sequences but with grain size and mineral sorting, may be beach deposits. Alternatively they may have been deposited by ephemeral streams that were generated during flash floods (Frostick and Reid, 1977) and prograded into the margin of the lake. The disturbance of the delta and beach sands by plant rootlets suggests that vegetation flourished around the edges of the lake.

(J) PEBBLY MUDSTONE LITHOFACIES

Description of lithofacies J: This lithofacies is rare and has only been noted in the Overfall Brook Member (Figure 22) and the Jeffrey's Village Member at Flat Bay (Figure 23, Section H). In the Overfall Brook Member it occurs with gray beds of lithofacies H or lies upon red siltstones. In the Jeffrey's Village Member, it is associated with interbedded green-gray sandstones and siltstones within dominantly red, shaly siltstones of lithofacies K.

The lithofacies is composed of poorly sorted, gray mudstone with silt, sand and grit particles, and muddy, gritty sandstone; bed thickness is 30 to 70 cm. The beds have sharp, undulose bases with no evidence of erosion or incorporation of underlying beds. The mudstones are internally structureless and ungraded. The granules are mostly 2 to 4 mm, angular, unoriented quartz and feldspar grains, but some 1 cm pebbles also occur. The pebbly mudstones contain carbonized plant remains.

Interpretation of lithofacies J: Poorly sorted, structureless diamictites with nonerosive bases that make up this facies are probably mudflow deposits. The lateral extent of the deposits is not known but the facies associations

Plate 82: Red shaly siltstone of lithofacies K with beds and lumpy layers of carbonate, Flat Bay section, Jeffrey's Village Member, Robinsons River Formation.

and thin development suggest both that the lateral extent is small and that the flows are of local origin. They probably formed by the failure and mixing of deposits of gravel, sand and mud that had soaked up floodwater or rainwater. In the Overfall Brook Member, slumping produced a mud slurry which flowed into adjacent depressions such as small lakes and abandoned, partly filled stream channels. In the Flat Bay section, the diamictites were laid down on playa flats. This suggests that they were formed by mobilization of deposits at the foot of a nearby alluvial fans.

(K) RED SHALY SILTSTONE LITHOFACIES

Description of Lithofacies K: **Important sequences of this lithofacies are found in the Jeffrey's Village Member at Flat Bay and in the Mollichignick Member. In both members, the facies is associated with both marine and nonmarine lithofacies (Figure 23, Section H, and Figure 28, Sections A and B). Sequences vary from <1 m to 115 m thick.**

The lithofacies is composed of red or gray, calcareous shaly siltstones, red, coarse siltstones and very fine sandstones, and carbonates (Plate 82). Red shaly siltstones predominate. They possess a poor to good fissility, and fine, flat to undulose lamination. Rare massive beds interrupt the shaly deposits, particularly in the Mollichignick Member. Interbedded in the shaly siltstones at 3 to 10 cm intervals are beds of calcareous, coarse siltstone and very fine sandstone. These beds are rarely greater than 10 cm thick in the Jeffrey's Village Member, but are up to 25 cm thick in the Mollichignick Member. They lie both gradationally and sharply within the shaly siltstones and are locally erosive. **Bedding in the siltstones and sandstones is wavy and lenticular. The main sedimentary structures are cross-lamination, wavy lamination and, in the thickest beds, crossbedding that infills broad shallow scours. Mudcracks occur in the redbeds of both members.**

The carbonates consist of nodular layers and beds 1 to 4 cm thick. They are red and gray in color and are composed of microspar and detrital silt grains. Lithological contacts may be diffuse and irregular, but more commonly bases are sharp and flat and tops are somewhat rough. Many beds show no structure whilst others clearly are grain size graded, with wavy, coarse, indistinct lamination passing up into finer lamination. Green reduction spots, vugs, and fine, randomly oriented fractures are common. The vugs are lensoid, spherical or bird's-eye shaped and are filled with coarse white spar; the fractures are also filled with spar. Many thin carbonate beds at Flat Bay also contain systems of 1 mm, spar-filled tubules which branch across and through the beds. Small clusters of millimetre-size, rhomboid pseudomorphs after gypsum occur in one carbonate bed just above the marine limestones low in the Flat Bay section (Figure 31).

In the Mollichignick Member, beds and laminae of dolomitic limestone and dolomite are interlayered with drab gray siltstones in the redbed units. The 10 to 38 cm thick dolomite beds consist of fine lamination and thin stratification. Laminations are disrupted by dessication cracks with polygon edges curled up. In some beds, the laminated dolomites have been reworked to form local intraformational breccias.

Interpretation of lithofacies K: This lithofacies contains the characteristics of a highly oxidized, low-lying, playa flat. From the associated lithofacies, it appears to have been deposited adjacent to a shallow marine or lacustrine shoreline and to have been flanked on the landward side by alluvial fans. The fine lamination of the siltstones and the thin sheets of coarser detritus, including graded silty carbonate beds that display lamination, suggest that sediment was transported and deposited by shallow sheetfloods. The fine detritus was probably derived from adjacent alluvial fans and by reworking of syndepositional carbonate units (cf. Eugster and Hardie, 1975). Minor channels represented by the somewhat thicker cross-bedded sandstones locally crossed the mudflats.

The playa flats were calcareous. This is particularly true of the Flat Bay section of the Jeffrey's Village Member where carbonate beds are more common than in the Mollichignick Member. Many of these beds may have been precipitated during dry seasons from groundwaters saturated with calcium bicarbonate. Some of the carbonates resemble caliche limestones whilst others were probably soft carbonate muds (cf. Eugster and Hardie, 1975) that were easily reworked to form graded, laminated beds. The general absence of sulfate minerals in the facies suggests that evaporitic conditions rarely prevailed in the mudflats of the Jeffrey's Village Member; exceptions are in beds that lie near marine units, as do those at Flat Bay. Laminated dolomitic limestones and dolomites in the Mollichignick Member were formed by algal mats that grew in shallow pools when the mudflats were flooded with seawater. When the pools dried up the mats were dessicated and produced mudchip-breccias.

(L) BEDDED MUDSTONE-SILTSTONE/SANDSTONE-CARBONATE LITHOFACIES

Description of lithofacies L: Gray siliciclastics associated with carbonates occur in units up to 6.5 m thick in the Mollichignick Member (Plate 83; Figure 27). In this member, the lithofacies includes dull gray, calcareous mudstone and shale, gray, micaceous, coarse siltstone or very fine sandstone, and yellow weathering, calcic dolomite and dolomitic limestone. In the Highlands Member there are two units, 90 and 300 cm thick, in which red-mottled, green mudstone is overlain by ripple cross-laminated and planar laminated, white, quartzose sandstone; the sandstone is capped by gray, wavy bedded, fossiliferous limestone (Figure 24, Section A and B)> The facies is also developed for a few metres above JVL-2 limestone on Fischells Brook (Figure 28) and above the Crabbes limestone at Crabbes Head (Figure 31). In both instances, the facies consists of coarsening-upward sequences of red or red and green mottled mudstones and siltstones, and ripple cross-laminated and laminated red and gray fossiliferous quartzose sandstones. The coarsening-upward sequences are capped by thin fossiliferous limestones and calcretes. Buff weathering, fossiliferous, massively bedded quartzose sandstones overlying dolomitic, fossiliferous packstones, and capped by calcrete, occur in the Jeffrey's Village Member along the North Branch River near the "round valley", Codroy lowlands.

The siliciclastic rocks in the Mollichignick Member are micaceous. They consist of lenticular beds of coarse siltstone or very fine sandstone, which are up to 30 cm thick (Plate 84) and are separated by 3 to 10 cm of black shale or mudstone with siltstone laminae. Many of the siltstone beds overlie the mudstone gradationally. The coarser beds have mostly planar to undulose thin stratification in which there is compositional and grain size grading. Scour and fill structures also occur, together with small crossbeds, cross-lamination, convolute bedding and wavy and flaser bedding (Reineck and Wunderlich, 1968). The cross-lamination is associated with rib-and-furrow structures and straight to sinuous ripple-marks, and there are both shale and coal flasers. Compositional and grain size grading occurs in the thin stratification. Trough-shaped scour and fill structures, up to 150 cm wide and trending northwest-southeast, are filled symmetrically by thin stratification.

Yellow weathering calcic dolomite, dolomitic limestone and gray limestone form lenses and beds, 10 to 60 cm thick, within the gray siliciclastic rocks of the Mollichignick Member (Plate 83). The carbonates vary from lime mudstones to argillaceous, skeletal wackestones and packstones (Dunham, 1962). Internally, they are thinly stratified, laminated or structureless (Plate 85). Tepee structures (Asserretto and Kendall, 1977), dessication cracks and local mudchip-breccias occur at the tops of laminated beds. Single or locally clustered nodules of blocky calcite spar occur with pink gypsum crystals in some of the carbonate beds (Plates 83 and 85). They resemble the calcitized nodules, after anhydrite, described by Lucia (1972). Fenestral and intra-particle porosity (Choquette and Pray, 1970), and tubular burrows, 0.1 to 0.5 mm in diameter, also occur.

Skeletal components include whole and fragmented ostracods, small planispiral and high-spired gastropods, bivalve shell fragments, crinoid ossicles, the sedentary foraminifera *Tubertina* (Mamet, 1970) and vertebrate fragments. The skeletal grains are mixed with indistinct micritic peloids and both allochems are set in a dark brown lime mud matrix that locally contains dark carbonaceous films of probable algal origin and scattered 0.02 mm dolomite rhombs.

Dissolution of mollusc and ostracod shells produced moldic porosity in skeletal layers, which is filled by blocky spar. Shell chambers are lined with fine, acicular druses and the remaining open spaces are closed by blocky spar. Partial collapse of some shells predated precipitation of the blocky spar.

In the Highlands Member, the carbonates are clean, sandy grainstones and peloid-rich packstones. The beds are structureless to wavy bedded with local brecciation. Mudcracks, tepee structures and brecciation affect thin planar stratification at the tops of the limestones. The grainstones include siliciclastic grains mixed with abundant whole and fragmented skeletal grains, oncolites and intraclasts. Skeletal fragments include high-spired gastro-

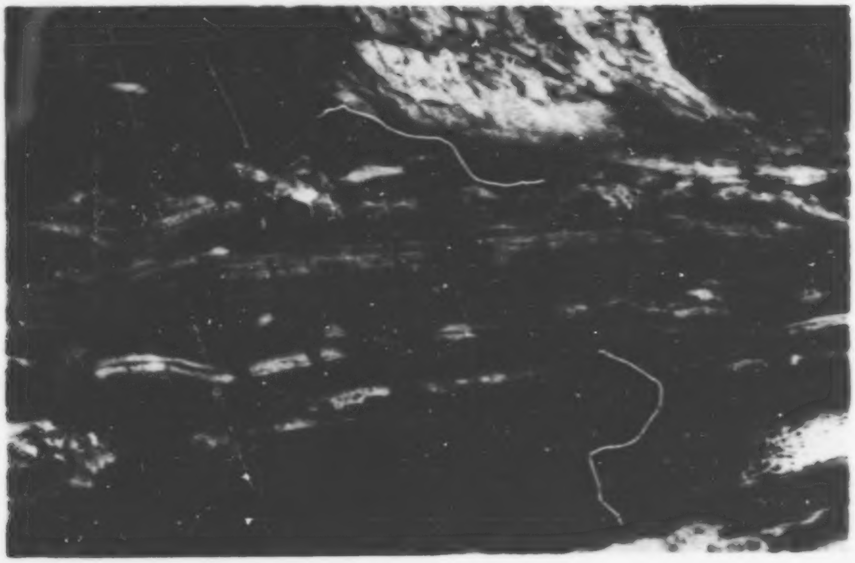


Plate 83: General view of lithofacies L, Mollichignick Member, Robinsons River Formation (Section C, Figure 28). Carbonate beds are interbedded with micaceous sandstone and shales in foreground; thick, crossbedded sandstone (lithofacies Q) occurs in the background above beds that belong to lithofacies M. Spherical solution pits in the bedded dolomitic limestones mark the sites of calcified anhydrite nodules. Southeast bank of Grand Codroy River, opposite Limestone Brook.

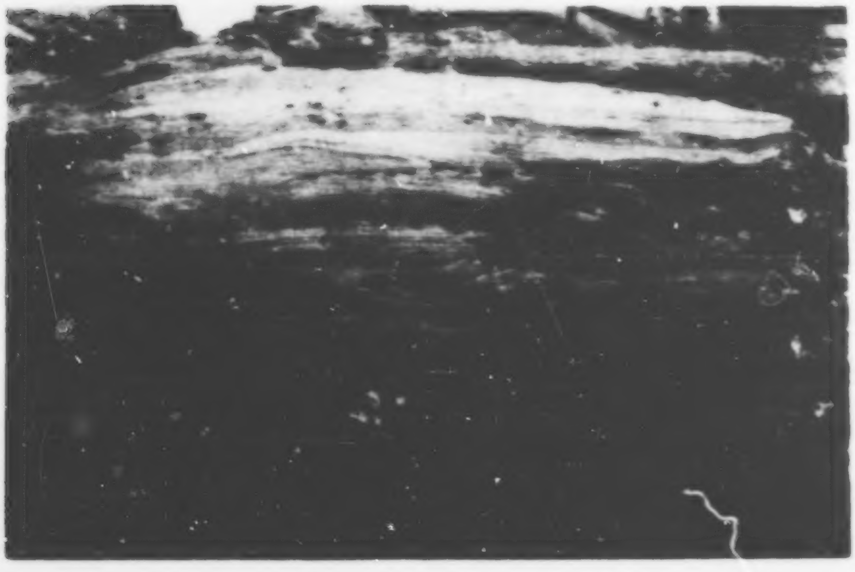


Plate 84: Laminated sandstones of lithofacies L, Mollichignick Member, Robinsons River Formation, location opposite Limestone Brook on the Grand Codroy River. Note scour surfaces and local convolution. Ripple cross-laminated sandstones overlie the laminated bed.

pods, ostracods, calcispheres, colonial dasycladacean algal cysts (Marszalek, 1975) and numerous foraminifera similar to *Pseudoglomospira* sp? (cf. Mamet, 1970). Cloudy micritic peloids and coated carbonate grains are also common. Acicular cements line ostracod shells but most porosity within or interstitial to grains is filled by clear calcite spar. Micritization of grains is common and the edges of some unicrystalline (crinoid ?) calcite grains have been partly replaced by micrite. The mollusc *Aviculopecten* and, in the "round valley" (Codroy lowlands), the bryozoan *Streblopteria biformata* (Bell, 1929; Moore and Ryan, 1976) occur in the siliciclastics and carbonates of the Jeffrey's Village Member.

Interpretation of lithofacies L: In the Mollichignick Member, the siliciclastic rocks have a high mica content and the mudstones are intercalated with siltstones and sandstones, so that there is a resemblance to the lacustrine deposits of lithofacies I. The presence of carbonates containing a marine fauna, however, indicates deposition in a marine or brackish marine environment. Flaser, wavy and lenticular bedding in the siliciclastics also indicates shallow marine, nearshore sedimentation (Reineck and Wunderlich, 1968). The environment was probably a shallow bay or lagoon, into which micaceous, muddy detritus was carried by shallow streams and rivers. Evidence of the latter is provided by the thick unit of crossbedded sandstones (lithofacies O) which overlies the marine deposits (Figure 27, section B).

Plate 85: Close up of gray, calcareous shaly mudstone overlain by stratified, dolomitic, skeletal packstone and wackestone seen in plate 83. Fossil debris at base is arrowed. Calcified anhydrite nodules in the middle of the bed are also arrowed.

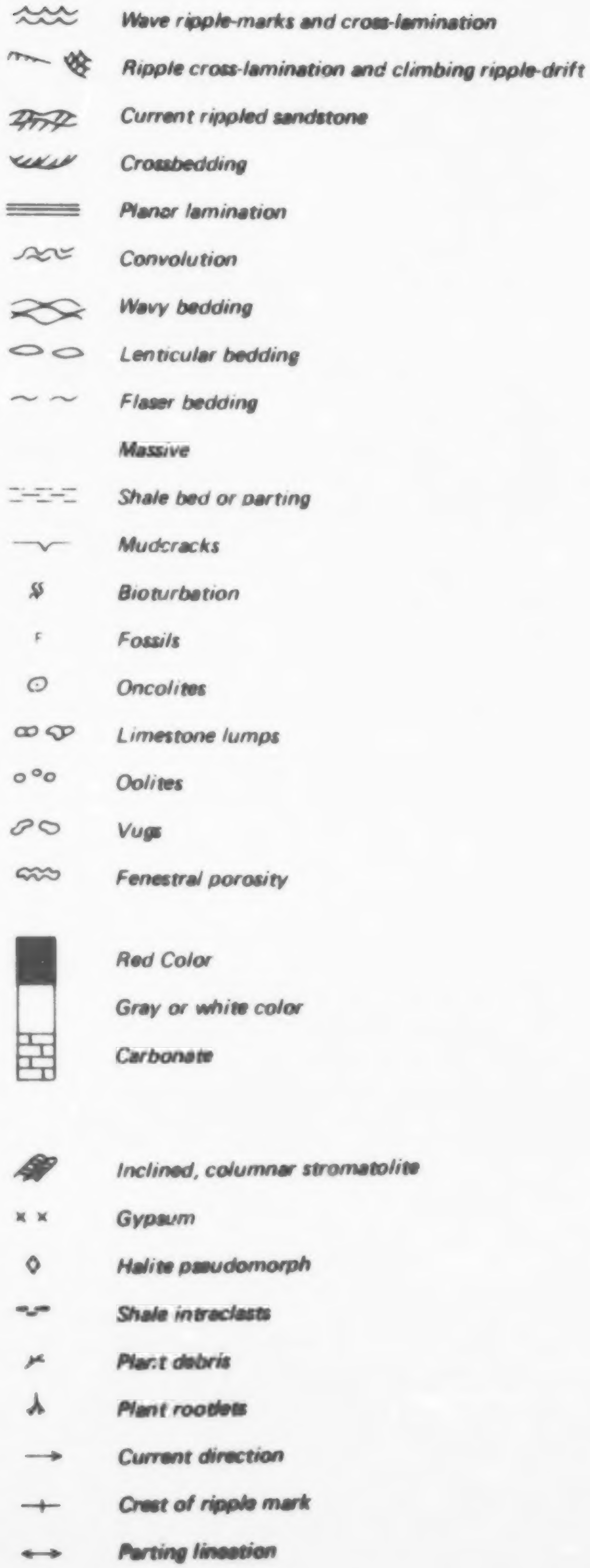
At times when there was little detritus reaching the bay or lagoon, it became the site of carbonate deposition and hosted a shelly fauna dominated by ostracods and gastropods. The crinoid ossicles suggest that at times the marine waters had near normal salinity (Horowitz and Potter, 1971; Heckel, 1972). The dominant shelly faunas, however, could also have thrived under brackish or hypersaline conditions (Heckel, 1972).

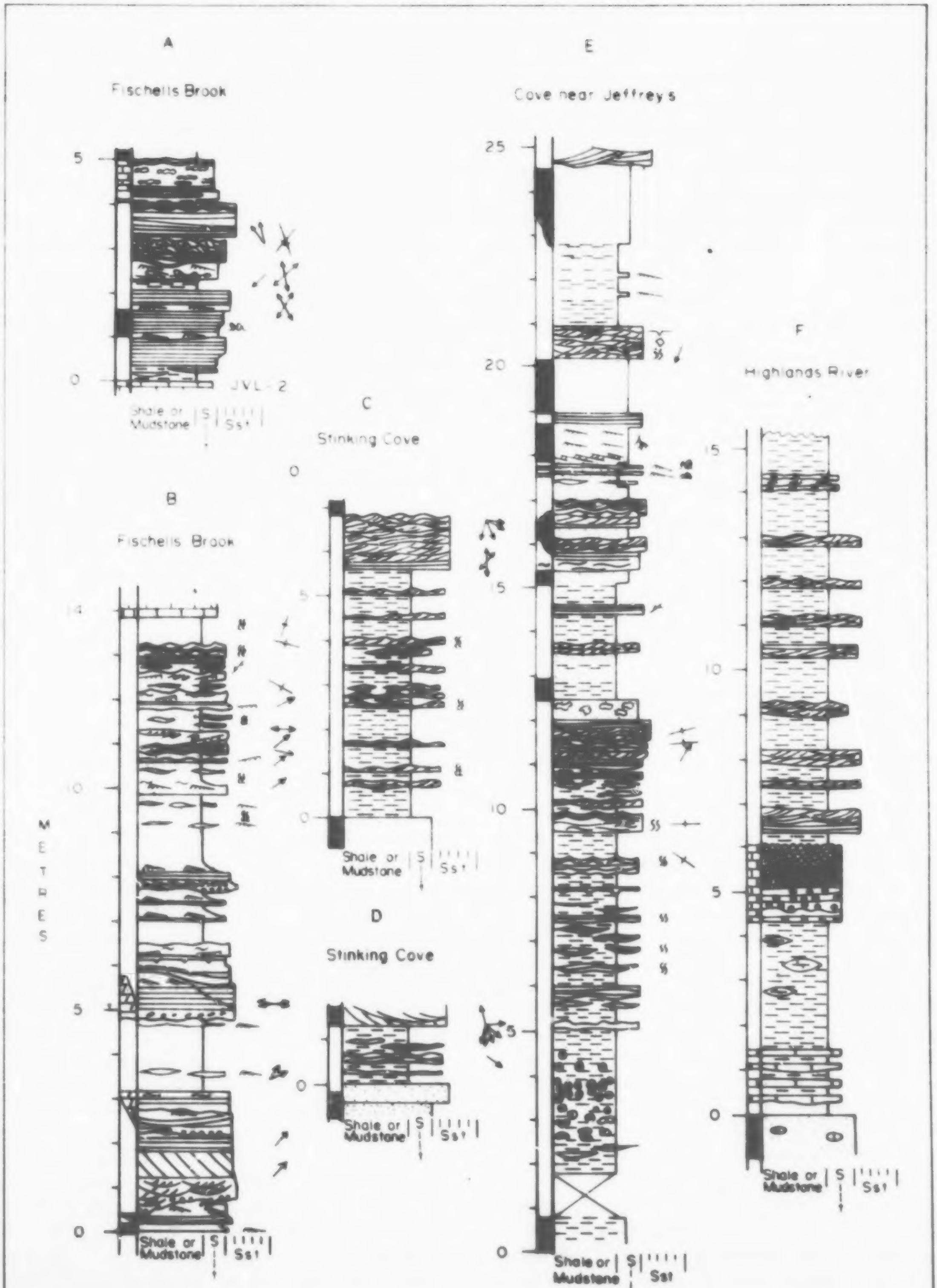
Carbonaceous laminae suggest that algal mats helped bind sediment in the shallow lagoons, and carbonates accumulated on the algal flats as the lagoonal muds became emergent with regression. Small tepee structures (Asserretto and Kendall, 1977), calcitized anhydrite nodules and partially dolomitized limestones suggest that the algal flats were subject to penecontemporaneous, diagenetic processes typical of modern sabkhas (Shearman, 1966; Kendall and Skipwith, 1968; Kinsman, 1969).

The acicular microspar druse in intraparticle and shelter porosity suggests early cementation that was either shallow subtidal or else marine vadose in the intertidal zone (Taylor and Illing, 1969; Shinn, 1969). Dissolution of shelly material and nodular anhydrite in the carbonates, and precipitation of clear blocky spar in the resulting porosity, probably records later freshwater diagenesis and cementation with the onset of nonmarine conditions.

The coarsening-upward sequences in the Jeffrey's Village and Highlands Members are interpreted as the product of a shallow prograding shoreline. Deposition of shallow lagoonal muds was followed by accumulation of well sorted, ripple-bedded, shoreline or sandbar siltstones and sandstones. These were superceded by deposition of low energy, lagoonal peloidal packstones and in the Highlands Member also by higher energy, fossil-bearing sandy grainstones. The fauna of calcispheres, ostracods, gastropods and abundant *Pseudoglomospira* indicate relatively high salinities (Mamet, 1970; Marszalek, 1975). Tepee structures and brecciation of the thin stratification at the tops of the limestones suggest algal flats that were subject to vadose diagenesis as the carbonates became emergent (Asserretto and Kendall, 1977).

LEGEND for FIGURE 28


Wave ripple-marks and cross-lamination
Ripple cross-lamination and climbing ripple-drift
Current rippled sandstone
Crossbedding
Planar lamination
Convolution
Wavy bedding
Lenticular bedding
Flaser bedding
Massive
Shale bed or parting
Mudcracks
Bioturbation
F
Fossils
Oncolites
Limestone lumps
Oolites
Vugs
Fenestral porosity
Red Color
Gray or white color
Carbonate
Inclined, columnar stromatolite
Gypsum
Halite pseudomorph
Shale intraclasts
Plant debris
Plant rootlets
Current direction
Crest of ripple mark
Parting lineation


A
Fischells Brook
5
0
JVL-2
Shale or Mudstone
S
Sst
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Fischells Brook
14
10
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METRES
Shale or Mudstone
S
Sst
C
Stinking Cove
5
0
Shale or Mudstone
S
Sst
D
Stinking Cove
0
Shale or Mudstone
S
Sst
E
Cove near Jeffrey's
25
20
15
10
5
0
Shale or Mudstone
S
Sst
F
Highlands River
15
10
5
0
Shale or Mudstone
S
Sst

Figure 28: Detailed sedimentological sections in lithofacies M and T, St. George's Bay lowlands. Sections also include rock types from marine carbonate lithofacies and nonmarine redbeds. The location of sections A, B and E is given in Figure 20.

(M) GRAY SHALE/MUDSTONE - SILTSTONE/ SANDSTONE LITHOFACIES

Description of lithofacies M: Lithofacies M is composed of shales or mudstones that are interbedded with lenticular and evenly bedded, coarse grained siltstones and fine grained sandstones. The shales and mudstones are gray, gray-green or black, and the siltstones and sandstones are gray but weather buff. The lithofacies occurs in units 1 to 8 m thick and is well developed in both the Jeffrey's Village (Plate 86; Figure 28) and Mollichignick Members (Plate 87; Figure 27, Section A and B).

Two associations occur: the first, in both members, consists of shales and sandstones in coarsening-upward sequences; the second, which occurs only in the Jeffrey's Village Member (Figure 28), consists of siltstones and mudstones intercalated with sandstones.

In the first association, repetitive coarsening-upward sequences, each up to 100 cm thick, are composed of shales or mudstones and sandstones. Shales near the base of the sequences give way upward into lenticular or evenly bedded (2 to 3 cm) sandstones below one or more 10-25 cm thick beds of sandstone. In both the Stinking Cove and Crabbes Head sections, the younger sequence is capped by 120 cm thick sandstone beds (Figure 28).

The black and gray generally fissile shales commonly contain oncoliths and fossil-bearing, carbonate concretions, 1 to 2 cm in diameter; scattered fossils are also present. The fossils in the Jeffrey's Village Member include gastropods, probably *Spirorbis*, the bivalve *Lithophagus poolii*, the branchiopod *Leaia*, the coral *Paraconularia* and the bryozoan (?) *Palaeocrisidia (Nodosinella)* (Bell, 1948, Fong, pers comm., 1976; Moore and Ryan, 1976). Bivalves identified as *Edmondia hartii* and *Aviculopecten* cf. *lyelli*, (McGlynn, personal communication, 1978), compacted unidentifiable brachiopods, inarticulate brachiopods, gastropods, some ostracods, a few pentagonal crinoid ossicles and a straight cephalopod were noted in shales of the Mollichignick Member. The shales are bioturbated, but this is not readily seen except where convex hyporelief (Basan, 1978) has preserved trails and burrows at the bases of sandstone beds. Bioturbation, probably by bivalves, completely disrupted and mixed some beds in the Mollichignick Member on Mollichignick Brook.

Sandstones are generally well sorted, very fine to fine grained, and rich in mica, fine plant debris and gray, discoid shale clasts. In the middle of the sequences, wavy bedded and lenticular sandstones have sharp erosional bases and flat or rippled tops. The sandstones at the tops of the coarsening-upward sequences also lie erosively upon the underlying strata, although in some sequences there is a gradation from shale to sandstone and the scour is developed midway through the sandstone. Internally, the sandstones have flat, undulose and gently inclined laminations, some of which carry parting lineations. There is also ripple cross-lamination, flaser bedding, and some small scale trough-and planar crossbedding. Convolute bedding causes hummocky tops in some of the beds, and there are many small scale, straight to sinuous ripple-marks which bifurcate and locally interfere with one another. In the Jeffrey's Village Member, bedding planes are roughened by bioturbation which includes burrows that are meandering and tubular or funnel- and plug-shaped (Frey and Howard, 1970; Chamberlain, 1978). U-shaped burrows (Plate 88) similar to *Arenicolites* and *Diplocraterion* (Frey and Howard, 1970; Chamberlain, 1978) and fine *Chondrites* patterns are common in the Mollichignick Member, as are randomly oriented tubular burrows.

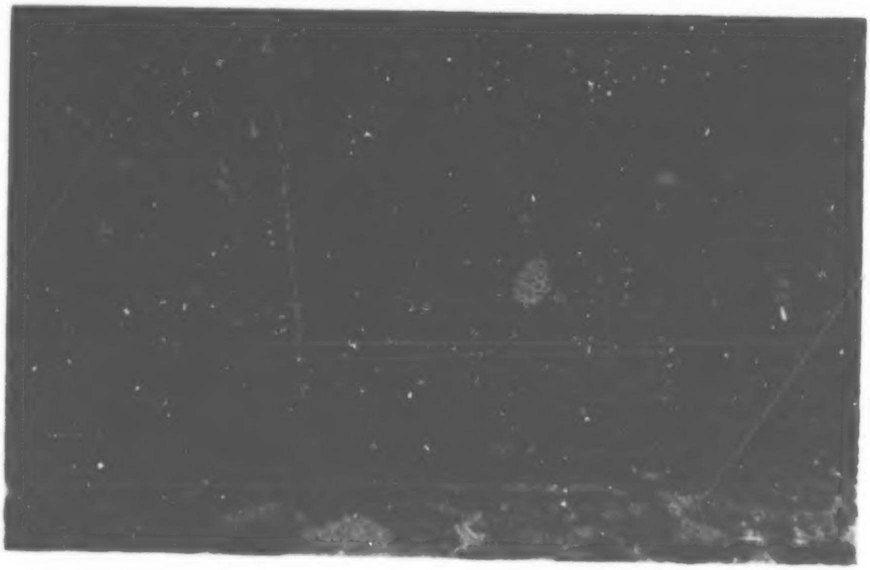


Plate 86: Thick sequence of lithofacies M in the Jeffrey's coastal section of the Jeffrey's Village Member, Robinsons River Formation. The section is composed of several coarsening-upward sequences of shales and sandstones. Algal oncolites and limestone lumps found in shale near base (circle). Ripple-marked bedding planes occur in the sandstones at the top of the section.

Plate 87: Thick sequence of gray to black shales, sandstones and some carbonates of lithofacies M, Mollichignick Member, Robinsons River Formation, Grand Codroy River (section A2, Figure 27). Sequences that coarsen upward occur above hammer. Red shaly siltstones (lithofacies K) are below the marine beds, lower right hand corner of plate.

Plate 88: U-shaped burrows and fine tubular burrows (upper part of bed) in well sorted, laminated and bedded white quartzose sandstones of lithofacies M, Mollichignick Member, Robinsons River Formation. Grand Codroy River near Limestone Brook.

Halite pseudomorphs, spherical molds after anhydrite (?) and some thin gypsum beds, 1 to 2 cm thick (Figure 28, Highlands Section) are locally associated with the facies.

The second association occurs in the 17 m immediately beneath the Fischells limestone (Figure 28) and consists of three fining-upward sequences 4 to 6.5 m thick. These are formed of green-gray sandstones and siltstones, and gray mudstones. Some of the sandstones are dolomitic and weather buff-yellow, and others are flaser bedded. Ripple-marked, calcareous, silty fine sandstones occur toward the top of the upper sequence. Siltstones interbedded with the mudstones are graded.

The bases of the sequences are each marked by an irregular scour. Well sorted, very fine sandstones and coarse siltstones, 60 cm to 2 m thick, occur above the scours. They display planar thin stratification and lamination, with good to indistinct parting lineations. They also have ripple-drift cross-lamination or small, trough-crossbeds, 5 to 10 cm thick and 50 cm long. Mudclast lags, some with good imbrication giving flow direction to the southwest and northwest, lie along the basal scours. Large planar crossbeds, 60 to 100 cm thick, form the tops of the sandstones and are capped by planar lamination of the upper flow regime, or by ripple cross-lamination. Shale flasers and partings occur in the upper parts of the sandstone beds.

A channel is eroded into dolomitic sandstone at the base of the second fining-upward sequence of this section. It is filled by several 15 cm beds of planar laminated sandstone (Plate 89) that thicken into the channels but thin as they drape over the channel edges. The sandstone beds are separated by mudcracked mudstone drapes, 1 to 3 cm thick which have been reworked locally to form intraclasts in the sandstone as it is traced laterally into the channel.

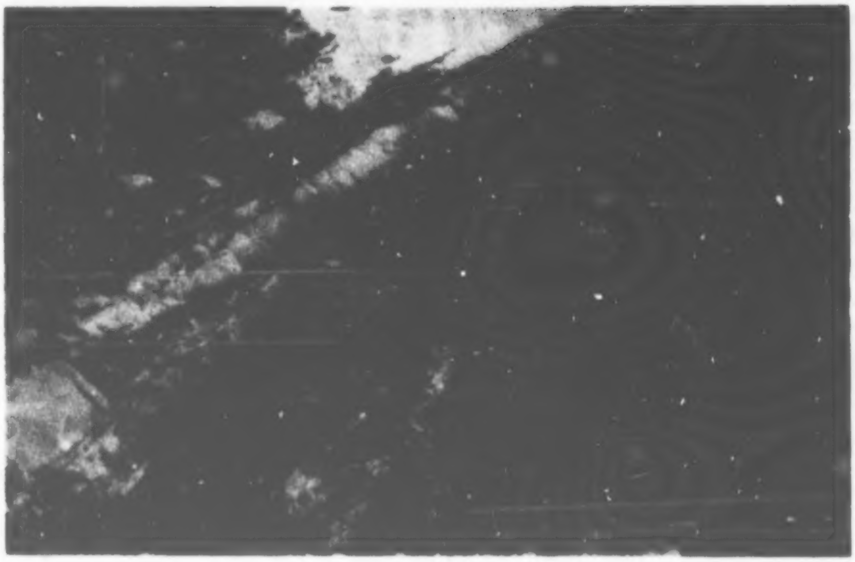


Plate 89: Thick, planar stratified sandstone interlayered with mudcracked thin mudstone layers, lithofacies M, Jeffrey's Village Member, Robinsons River Formation below Fischell's limestone, Fischells Brook. The bedded sandstones and mudstones fill a channel eroded into carbonate cemented, planar stratified sandstones.

In each sequence, the planar laminated sandstones are overlain by beds of silty, very fine sandstone up to 42 cm thick. These show flaser bedding, ripple cross-lamination, and flat lamination, and contain lenses and beds of mudstone. The flaser bedded sandstones are, in turn, overlain by graded beds of siltstone and mudstone, 35 to 215 cm thick. The siltstones have sharp, flat to irregular scour bases and are laminated and ripple cross-laminated. Shale flasers occur increasingly toward the top of siltstones and thin siltstone layers, and lenses occur in the overlying mudstones. The mudstones are structureless except for some silt streaks and dolomite laminae. Fine burrow-mottling occurs locally at the tops of the mudstones in the second and third fining-upward sequences.

Ripple-marked, calcareous, silty, very fine sandstones are interbedded with the mudstones in the upper sequence to form some coarsening-upward couplets. Internally, they appear massive but also have fine wavy lamination, festoon ripple cross-lamination, shale flasers, and some irregular burrows. Straight, symmetrical ripple marks, interference ripple marks and rain pits occur on the tops of beds.

Current directions in the second association are to the northeast or east, except where has been otherwise noted.

Interpretation of lithofacies M: The first association of lithofacies M contains a record of repetitive low and high energy deposition in a restricted marine setting. Quiet water shales suggest a protected environment such as a back-barrier lagoon (Hayes and Kana, 1976; Reinson, 1979). Carbonate concretions and beds, halite and gypsum pseudomorphs, gypsum beds and the low density, small infauna show that salinities varied considerably (Elliott, 1978b). The branchiopod, *Leaia* (Bell, 1948), may be a brackish water form (Heckel, 1972), but other species and the abundant bioturbation are consistent with near normal marine conditions for much of the time. The ichnofossils are generally similar to those expected in nearshore or lagoonal environments (Howard, 1972; Chamberlain, 1978).

Interrupting the dominantly quiet sedimentation were episodes of deposition of fine sand and coarse silt. Gradational bases in some thicker sandstones and the gradual coarsening upward due to the increase of thin sand lenses and beds in the shales suggest progradation of sands over the lagoonal muds. Erosion at the base of or within sandstones indicates that high energy storm events periodically affected the lagoons. Sand deposits filling modern back-barrier lagoons include washover fans, tidal sand flats and deltas, aeolian dunes, small deltas and prograding beach deposits (Klein, 1975; Hayes and Kana, 1976; Barwis, 1976; Elliott, 1978b). Small scale sedimentary structures support intertidal flat to beach environments for these sand deposits. The most diagnostic of these structures are ripple-marks, ripple cross-lamination, flaser bedding and low angle, undulose to flat lamination. Lagoons form behind physical barriers, which in this case were either algal banks (Figure 28), or sand spits and barrier sands, since the overall succession is dominated by terrigenous nonmarine sediments.

The thickness of the shale-sandstone couplets and of sand bodies in this lithofacies suggests tidal ranges were probably less than 100 cm and hence microtidal (Hayes and Kana, 1976; Davis, 1978). The repetitive deposition of shale and sandstone couplets over several metres implies that although shallow, the lagoon was maintained by steady subsidence.

The second association, located below the Fischells limestone, was also deposited in a shallow marine nearshore setting. A marine aspect is supported by the stratigraphic position of the section below the Fischells limestone. In addition, flaser and lenticular bedding, bioturbation, symmetrical and interference ripple marks and bimodal paleocurrents suggest the sediments were laid down in the intertidal zone. Unlike the sequences of the first association, however, those of the second fine upward and consist of scour-based, crossbedded and planar stratified sandstones that are overlain by flaser bedded fine sediments. These fining-upward sequences resemble closely those described in prograding tidal flats (Reineck, 1975; Elliott, 1978b). The current-bedded sands which also have a basal mudchip lag deposit and locally display channelling were likely deposited in the lower part of the tidal flat associated with migrating tidal channels. Overlying these sands, flaser bedded fine sediments were laid down on mudflats higher in the intertidal zone. Ripple-marked, flaser bedded, rain-pitted and bioturbated, calcareous siltstones overlying mudstones at the top of the section, just below the Fischells limestones, were, like association A, perhaps deposited in a shallow prograding shoreline. Alternatively, they represent deposits that formed still higher on the tidal flat perhaps similar to the inner sand flats described by Evans (1965, 1975) in the Wash, eastern England.

The basal sequence of the section overlies fluvial-deltaic red and green siltstones and sandstones implying that the marine environment transgressed over and probably reworked abandoned delta deposits.

(N) VARICOLORED MUDSTONE LITHOFACIES

Description of lithofacies N: The varicolored mudstone facies is found only in the lower part of the Jeffrey's

Village Member and is well exposed along Fischells Brook below the Fischells limestone (Figure 29, Sections A, C and D). It also occurs in tightly folded and faulted strata at Ship Cove, north of the Cormorant limestone. The facies units along Fischells Brook vary from 10 to 500 cm in thickness and there are at least eighteen units exposed. The facies is characterized by red, green-gray, blue-gray and black colored mudstones which may be slightly calcareous.

Two variations of the lithofacies occur. The first consists of mudstones with color bands that alternate on a scale of 1 mm to 5 cm, and the second of dark-colored mudstones in 160 cm units. In the rapidly alternating variety, the color changes coincide with slight variations in grain size and texture. Red layers are mostly massive mudstone whilst green-gray and blue-gray bands consist of coarse siltstone and mudstone with flat to microconvoluted, commonly discontinuous laminae. Black mudstones are thinly stratified with structureless and laminated layers. Red color bands are generally concentrated toward the tops and bottoms of the deposits with rapidly alternating color bands, although a few red bands also occupy the centres of these units.

Apart from the fine lamination and microconvolution, which is symmetrical and gives a fluffy bulbous appearance to laminae, sedimentary structures are rare in the varicolored laminite. Mudcracks were observed in only three units in the Fischells Brook section and were not encountered at the Ship Cove section. Cubic and some rhombic crystal molds are concentrated in thin beds or along specific laminae in the red mudstones, and less commonly the other color bands; they are pinpoint to 7 mm in size. The crystals molds are lined or filled by yellow weathering siderite.

A number of units consist completely of black mudstone (Figure 29, Section B). These mudstones are thinly stratified and have been affected by slump folds and sedimentary thrusts which distort major portions of the units.

Sequences of gray, very fine grained sandstone and black shale (Plate 90) occur in the laminated variety of the lithofacies on Fischells Brook (Figure 29, Section A). They are located at the bases and tops of two of the oldest units and are between 22 and 36 cm thick. The sequences consist of ripple-marked or wavy bedded sand sheets, 2 to 4 cm thick, separated by mudcracked black shale; the sandstones contain halite pseudomorphs. The ripple-marks are straight to locally branching, and there are some interference patterns. The crests trend about 070° and 130°.

Interpretation of lithofacies N: The fine textures, thin planar stratification, fine grain size and halite pseudomorphs suggest that this lithofacies was largely deposited subaqueously in a quiet hypersaline depositional environment. A shallow ponded environment is indicated by an exposure of varicolored mudstones that onlaps the edge of a bar-shaped sand deposit (see Section F, Figure 29 and Figure 30b), and by the association with rippled sandstone and mudcracked black shales. These two types of sedimentary deposit suggest that the ponds lay behind distributary channels or barrier sand bodies and were flanked on their landward edge by mud and sand flats resembling modern tidal flats (Reineck and Singh, 1975). Steady strong winds, which are known to drive water onto modern deltas (Oomkens, 1970) and mudflats (Schneider, 1975), were probably the main control of flooding, ripple generation (Tanner, 1967; Harms, 1969), and dessication of the landward, muddy sand flats. The rarity of mudcracks in the laminite units suggests that the ponds were not often completely dessicated. The basal and topmost development of red color bands supports gradual deepening and then infilling of

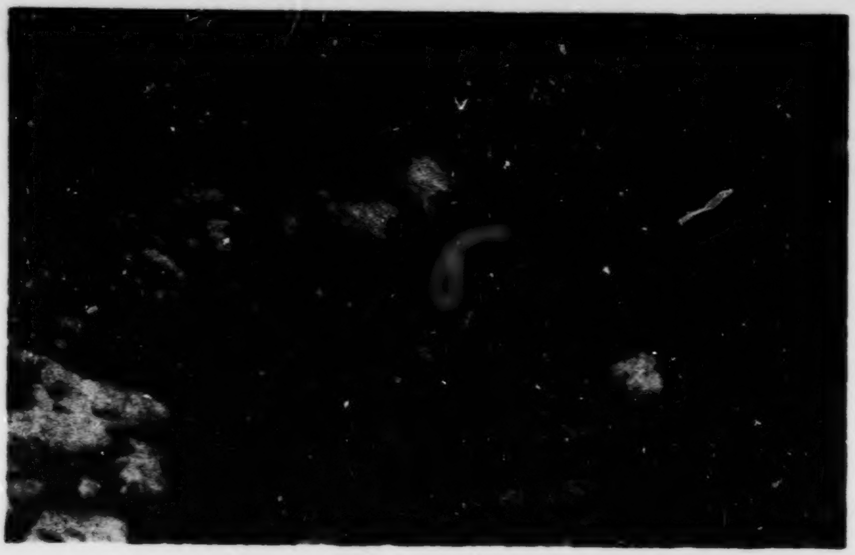


Plate 90: Varicolored mudstones of lithofacies N (at hammer) overlying ripple-marked sandstones that are interbedded with mud-cracked, black shale drapes. Both beds are sandwiched between brown and red, halitic siltstones and sandstones (lithofacies O). Lower part of Jeffrey's Village Member, Robinsons River Formation, Fischells Brook, 300 metres downstream of railway bridge.

the ponds. The oxidized red layers were laid down when the ponds were perhaps less than a few centimetres in depth or reduced to a damp playa flat. Darker colored mudstones were deposited in the deeper areas of the ponds. Slumping occurred on gentle slopes.

Fine halite and gypsum pseudomorphs imply the ponds were pereníally or periodically hypersaline. Laminae, composed mostly of 1 mm crystals, suggest precipitation and settling in the pond waters (Shearman, 1970), but large crystals scattered randomly in the mudstones may have formed by displacive growth (Smith, D.B., 1971; Shearman, 1978; Kendall, 1979a). Scarcity of evaporite minerals in the darker color bands implies dilution of pond waters by flooding, although it is possible that the gypsum was removed by sulfate-reducing bacteria which would have thrived in the anoxic waters indicated by the black mudstones (cf. Neev and Emery, 1967).

(O) HALITE-BEARING SILTSTONE-SANDSTONE LITHOFACIES

Description of lithofacies O: This facies includes muddy siltstones, coarse siltstones and very fine sandstones that are rich in small cubic molds after halite crystals (Plates 91 and 92); most of the rocks are brown, but some of them are gray and green-gray. The lithofacies occurs in 1 to 7 m thick units that are intercalated with varicolored mudstones (Section A, B, C and D, Figure 29) in the section below Fischells limestone on Fischells Brook, and also in continuous, though poorly exposed, sequences several tens of metres thick (Section A, Figure 29).

The lithofacies includes several types of deposits. Brown, massive, muddy siltstone is the most common rock type (Plate 91). It occurs in beds 50 to 500 cm thick, lying in many cases gradationally within varicolored mudstones. In some units, thinly developed, drab

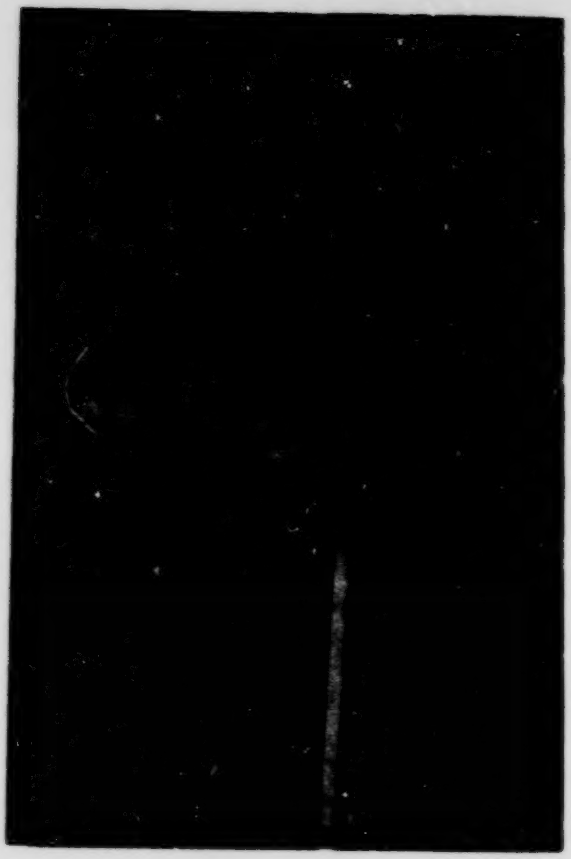


Plate 91: Bedded, halite-bearing, muddy siltstones of lithofacies O. Beds are dominantly structureless except for some faint lamination at base. Lower part of Jeffrey's Village Member, upstream of Fischells limestone, Fischells Brook.

gray, massive, silty mudstones lie between the varicolored mudstones and the brown siltstones. Cubic crystal molds, 1 to 5 mm in size, are distributed randomly throughout the mudstones.

The second type of deposit consists of sequences, 2 to 6 m thick, composed of graded beds of coarse siltstone and structureless, halitic, muddy siltstone. The coarse siltstones overlie a basal scour. Internally some of them have a thick interval of planar lamination without parting lineations, and this is overlain by a thin division with cross-lamination. Others have only ripple laminations, including some climbing types. Crossbeds occur locally. Some of the halitic muddy siltstone beds have indistinct bedding, and symmetrical convolute deformation, picked out by weathering, was noted locally (Figure 29, Section D).

The third type of deposit in the facies consists of brown, silty, very fine sandstones, 1 to 4 m thick. They have scoured bases, abundant internal erosion, some trough cross-stratification, plentiful ripple cross-lamination and some climbing ripple-drift. They also occur as sheet-like deposits of planar lamination with current lineations overlain by ripple drift. Silty sandstones that overlie both the rippled sandstones and mudcracked black shales of lithofacies N (Figure 29, Section A; Plate 92) are made up of a series of convex-upward wedges, 45 cm thick and several metres long. The wedges are constructed of crossbeds, with cross- and some planar lamination. They are stacked so as to offlap each other from east to west along the outcrop. Cross-lamination in the wedges has a west to northwest paleoflow and current lineations on the planar stratification give northwest-southeast flow trends.

Interpretation of lithofacies O: The various sediments of the lithofacies are interpreted to have accumulated on a playa mudflat which lay landward of the hypersaline ponds (lithofacies N). The massive muddy siltstones were laid down in distal areas of the mudflats, near pools; halite crystals were precipitated from saline groundwaters and grew displacively in the oxidized brown muds (cf. Smith, D.B., 1971; Shearman, 1978). The sheets of silt and very fine sandstone were deposited by shallow, ephemeral streams in the mid-part of the flats. Deposition was probably rapid with suspended sediment laid down as climbing ripple-drift (McKee, 1965; McKee et al., 1967).

Plate 92: Brown, ripple cross-laminated, very fine sandstone overlying halitic, red siltstone in sequence of lithofacies O. Laminated and ripple cross-laminated foresets of sandstone accreting laterally from tapering margin of earlier sandstone deposit. Fischells Brook, lower part of Jeffrey's Village Member upstream of Fischells limestone.

The thick sandstones with crossbeds and abundant scour and fill formed in ephemeral braided stream channels (Picard and High, 1973; Tunbridge, 1981a and b) that fed sand- and mud-size detritus to the middle and lower part of the mudflat. The convex-upward, offlapping sandstone wedges prograded over the marginal, muddy sand flats of the hypersaline ponds and were perhaps deposits of small aeolian magaripples that encroached along the edge of the ponds.

(P) GREEN-GRAY MUDSTONE-SILTSTONE LITHOFACIES

Description of lithofacies P: Lithofacies P consists of green and green-gray mudstones and siltstones that are found only below the Fischells limestone on Fischells Brook. They occur in units 1 to 3.5 m thick mostly associated with rocks of lithofacies Q.

Lithofacies P has three associations. The first association consists of massive green-gray mudstones, up to 240 cm thick, gradationally overlain by 27 to 45 cm of current-laminated, green-gray siltstones. The latter in turn underlie lithofacies Q sandstones to form coarsening-upward sequences overall (Figure 29, Section B and C). Climbing ripple-drift, ripple cross-lamination, and local convolution are typical of the upper siltstones; downcurrent the ripple drift passes into small scale crossbeds. Large, sand-filled cracks were noted in a mudstone unit that lies sandwiched between two thick lithofacies Q sandstones.

The second type of deposit is composed of 20 cm beds of interlaminated green-gray siltstones and mudstones, with some beds of green and gray massive mudstone.

The third association in this facies consists of graded beds, 30 to 90 cm thick, of siltstone and mudstone. The siltstones, which are mostly 5 to 20 cm thick, lie sharply or erosively upon the mudstones and have ripple cross-lamination, some climbing ripple-drift, and flat to wavy thin stratification. They grade up into structureless mudstones. The current-bedded siltstones decrease in thickness up through the sequences, some of which have mudcracks and reddening at their top.

Halite crystals are absent in the facies except where the section lies below the lithologies of lithofacies N and O, as in Section C, Figure 29. Here halite occurs at the base of a green - gray mudstone bed.

Interpretation of lithofacies P: The drab colored mudstones and siltstones of this facies, which are found only below the Fischells limestone, are interpreted to have been deposited in different delta subenvironments. The subenvironments included sheltered, shallow bodies of water associated with small, nontidal, fluvial-dominated deltas, and the subaerial delta plain environment where sediments were poorly drained and hence permanently waterlogged (Donaldson et al., 1970; Leeder, 1974; Ryder et al., 1976).

The first association of mudstones that grade up into current ripple-bedded siltstones is interpreted to have formed in front of distributary sand bodies. Rapid deposition is indicated by lack of structure in the basal muds and the presence of climbing ripple-drift (McKee, 1965) in the siltstones. Similar deposits have been reported in the Salton Sea ahead of bar finger sands of the New River Delta (Stephen and Gorsline, 1975). Finely laminated silts and muds of the second association were deposited by overbank flooding (Kanes, 1970; Donaldson et al., 1970; Elliott, 1975) in shallow sheltered bays and ponds on the delta top.

In the third association, decelerating density currents were probably responsible for the grading and sequential arrangement of cross-laminated siltstones below structureless muds. The currents probably formed when sediment-laden flood waters descended through levee-breaches from elevated, distributary channels. Their suspended sediment was spread out as crevasse-splay lobes or sheets into nearby bays or lakes (Elliott, 1975). Overbank flooding and channel crevassing higher on the delta plain produced similar graded deposits which were partly oxidized.

(Q) CROSSBEDDED SANDSTONE LITHOFACIES

Description of lithofacies Q: Green-gray, very fine to medium-fine grained sandstones, in units 2 to 8.5 m thick (Plate 93), compose this lithofacies. Sandstones dominate two separate sections (Figure 29, Sections B and D) along Fischells Brook below the Fischells limestone. Each section is 30 to 40 m thick. A single unit, 8 m thick, occurs in the Mollichignick Member (Plate 83; Figure 27, Section B). Grain size within individual sandstone units may be constant or it may fine upward. Some sandstones are composed of interbedded, lenticular sandstones and siltstones.

Characteristic of the facies as a whole, but particularly the ungraded sandstones, is the abundance of internal scouring, intraclasts and large, trough cross-sets. The latter can reach 50 to 150 cm in thickness. Large, planar crossbeds are common near the base of some units and may be interlayered with planar stratified beds toward the tops of many units. Ripple cross-lamination and climbing ripple-drift and convolution of sedimentary structures also occur. Parting lineations associated with the planar stratification, pockets of carbonized plant fragments and mica-rich layers are common. Most basal and internal scours

Plate 93: Thick, crossbedded, green-gray, very fine to fine grained sandstones of lithofacies Q (section B, Figure 29). South bank of Fischells Brook, in lower part of Jeffrey's Village Member, below Fischells limestone.

are irregular, although some are planar on an outcrop scale. In the scour hollows are pebble lags of green and/or red intraclasts that include blocks of siltstone up to 30 cm in size. Imbrication of intraclasts at the bases of some units gives an apparent southward paleoflow direction. Intraclasts are also concentrated along trough scours and foresets. Steep, curved foresets and scoop-shaped scours are characteristic of many trough-crossbeds. Some of these crossbeds have several erosion (reactivation) surfaces, each subparallel to the original scour and each overlain by a number of foreset laminae. Apparent reversal of crossbed direction has been noted in several sandstone units. This reversal commonly occurs above scours that have eroded previously deposited trough-crossbedded and planar stratified sandstones (Figure 30A). The paleocurrent directions indicated by the crossbeds are, however, dominantly to the south and southwest (Figure 32).

Scour and fill is typical of units that are composed of lenticular interbeds of sandstone and structureless siltstone. Sandstones, 70 cm thick, are enclosed in shallow, broad scours which crosscut both previously deposited sandstones and interbedded green shaly siltstones. Planar stratification overlain by trough cross-stratification generally composes the scour-based sandstones.

In sandstones that fine upward, there is a corresponding decrease in the size of sedimentary structures. The lower parts of the units have large trough cross-stratification, while in the upper parts there is planar lamination, ripple-drift cross lamination and small scale, symmetrical and overturned convolution. The sandstones mostly pass up into red, structureless siltstone (comparable to lithofacies A; see Figure 29, Section D). They are also associated with red, fine sandstones and siltstones and some planar cross-stratified sandstones and siltstones that bear a striking resemblance to deposits of lithofacies B and lithofacies D along Robinsons River (Figure 23, Section D).

Closely resembling the ungraded and fining-upward sandstones in color and grain size are sandstones that display well developed planar stratification. One such sandstone occurs in the Fischells Brook section in the transition from the lower sandstone upward into a section comprised mostly of varicolored and halite-bearing siltstones. The planar stratified sandstones, which are capped by a

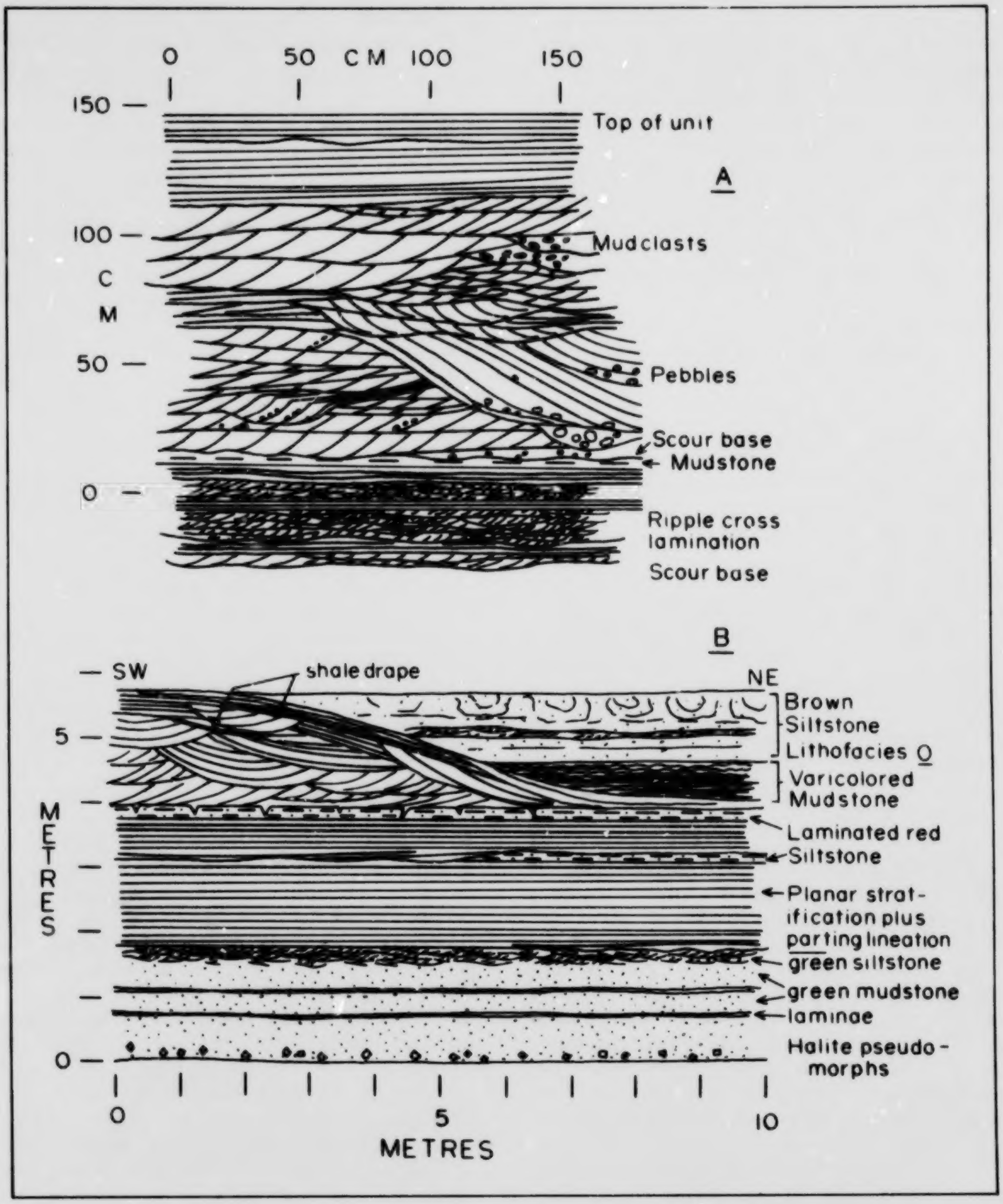

0
50
CM
100
150
150
100
C
M
50
0
Top of unit
A
Mudclasts
Pebbles
Scour base
Mudstone
Ripple cross lamination
Scour base
B
SW
shale drape
NE
5
METRES
0
Brown Siltstone Lithofacies Q
Varicolored Mudstone
Laminated red Siltstone
Planar stratification plus parting lineation
green siltstone
green mudstone laminae
Halite pseudomorphs
0
5
10
METRES

Figure 30: Notebook sketches of structures in lithofacies Q sandstones of the Jeffrey's Village Member, Fischells Brook. Sketch A is taken from a unit in the upper 10 m of section D, Figure 29, and shows the abundance of scouring and the apparent reversal of trough crossbed current direction. Sketch B is of a bar-shaped sand body (section C, Figure 29) which consists of sandstones overlying a type 1, coarsening-upward unit of green mudstone and ripple-laminated siltstone.

bar-shaped, crossbedded sandstone unit (Figure 29 and 30B, Section C) overlie green-gray mudstones and siltstones (lithofacies P). The planar stratified sandstones carry consistent parting lineations trending 176° to 356° and are separated into two beds by 15 cm of laminated, red, sandy siltstone. Mudcracked, laminated, red siltstone, 20 cm thick, separates the stratified sandstones from the overlying bar-shaped sandstone body. The latter is incompletely exposed but is 168 cm thick at the centre, tapering to 50 cm in the north; the southern margin is unexposed. It has a flat nonerosive base, with sand infilling mudcracks in the underlying siltstone, and the top is smooth and convex-upward. In the thickest part of the deposit trough-crossbeds give southerly apparent paleoflow directions. At the northern margin of the bar, however, directions are easterly trending, and northward inclined, mud-draped, planar or scoop-shaped scours are overlain by parallel beds (Figure 30B). The northern slope is onlapped by varicolored mudstones and halite-bearing brown mudstones and siltstones.

Interpretation of lithofacies Q: The ungraded and fining-upward units of crossbedded sandstones are probably the deposits of sandy, delta distributary and river channels.

The fining-upward sandstones are dominated by trough-crossbedding and are overlain by red, vertical-accretion deposits. These characteristics together suggest that these sandstones are the deposits of high sinuosity river channels as described by Allen (1965a, 1970a).

The ungraded sandstones, however, are markedly different in that they contain mudclasts and have abundant internal scouring associated with large trough, and some planar-crossbeds. These structures suggest that high energy flood events repeatedly washed out earlier sand deposits, and then deposited sands in the channel as large bars and sand waves (Harms, 1975). Planar stratified units with parting lineations were also laid down in the channels when flow velocities increased locally. Waning flow produced current-rippled deposits toward the end of some of the floods. Beds of climbing ripple-drift (Jopling and Walker, 1968) near the tops of some of the sandstones indicate that even as current strength was reduced, sediment supply was still high and deposition took place rapidly (McKee, 1965). Thin siltstone layers separating thick sandstone units suggest channels were abandoned or subject to only gentle flow between floods.

The ungraded sandstones occur in some instances as the upper members of coarsening-upward sequences. The sandstones overlie mudstones and siltstones of lithofacies P which are interpreted as prodelta deposits. This suggests that the ungraded sandstones were deposited in distributary channels. There is little evidence within the rock succession hosting these sandstones that tidal or wave action contributed to the character of the succession as a whole. Instead, the channel sandstones clearly have a fluvial aspect. It is probable therefore, that the rivers constructed elongate bar-finger sand bodies to form bird's-foot deltas (Fisk et al., 1954; Coleman et al., 1964; Kanes, 1970; Donaldson et al., 1970; Stephen and Gorsline, 1975). Frequent channel switching and crevassing (Elliott, 1975; Wright, 1978) is common in this type of delta. Evidence that such processes affected the ungraded sandstones of the Jeffrey's Village Member is provided by changes of paleoflow direction in crossbeds associated with major scours. It is supported by abrupt deposition of mudstone or siltstone beds upon large scale crossbeds within the sandstones.

Large mudcracks that occur in siltstones between two thick channel sandstones, suggest that channels were periodically abandoned and desiccated. Similar desiccation features are present in temporarily abandoned distributary channels of the New River delta, Salton Sea, California (Stephen and Gorsline, 1975).

The bar-shaped sandstone which is onlapped by varicolored mudstones and halite-bearing siltstones may also be a distributary channel deposit. The channel, however, would have been abruptly abandoned so that it became the site of a hypersaline pool which was infilled by the onlapping fine beds. Elongate salt pans have been described in an abandoned channel in the Colorado delta, Gulf of California (Meckel, 1975). The lack of lateral exposure prevents a full understanding of this deposit, and it is conceivable that it formed in a barrier island - chenier plain complex (Kraft, 1978) or as a marginal, beach ridge like that described from Lake Michigan (Fraser and Hester, 1977). In this model, shoreline beach deposits of planar stratified sandstones are overlain by a narrow ridge behind which are deposited varicolored mudstones and mudflat deposits (Meckel, 1975; Wright, 1978; Kraft, 1978). This would imply that distributary sandstones were reworked by shoreline processes, including storm-driven currents and waves, after delta progradation had ceased. The stratigraphic position of the bar-shaped deposit tends to support interpretation as a beach-ridge complex. It lies above the main delta sequences and below a sequence dominated by deposits of hypersaline ponds and mudflats. Clearly, therefore, primary control of sedimentation shifted from river-dominated processes to those of destructive shoreline reworking.

(R) MARINE CARBONATE LITHOFACIES

General definition of marine carbonate lithofacies: Limestone and dolomite occur in several units, 2 to 8 m thick, within the Jeffrey's Village Member (Figure 31). Marine carbonates in the Hollichignick and Highlands Members are described within lithofacies M. Limestones in the St. George's Bay lowlands, named by Bell (1948), are the Barachois, Fischells (Plate 94), Crabbes (Plate 95), Jeffrey's and Heatherton (Plates 102-103) limestones. Usage of some of these names has been continued (Figure 31) and unnamed limestones are identified by an initial and number, e.g. JVL-2. The Crabbes and Jeffrey's limestones were considered by Fong (1974, 1975) to be the same unit repeated by faulting; therefore the name Jeffrey's limestone is discontinued. The Crabbes limestone can be correlated northward with units at Stinking Cove and Muddy Hole (Bell, 1948; Fong, 1974; Fong and Douglas, 1975). Fossiliferous limestones in the "round valley", Codroy

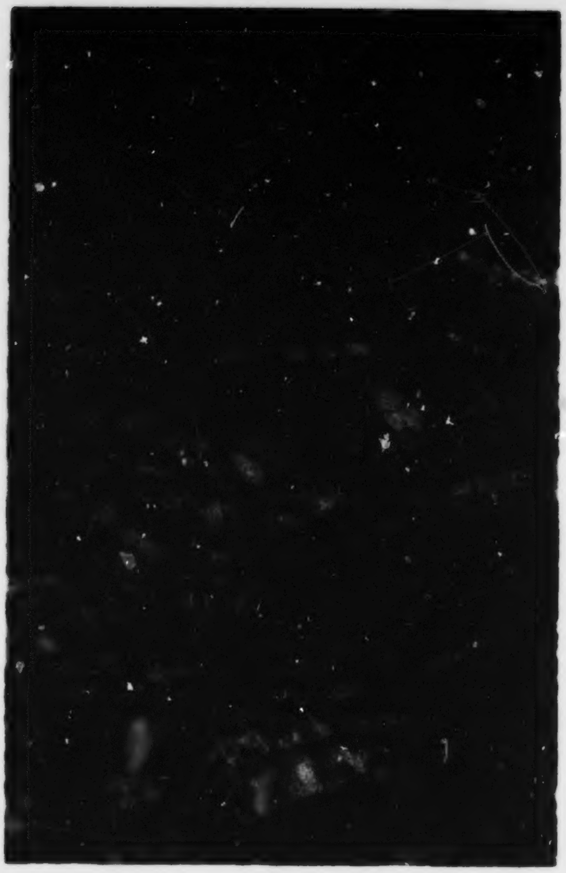


Plate 94: Fischells limestone, composed of dolomitic limestone beds and recessively weathered shales or mudstones. Jeffrey's Village Member, Fischells Brook.

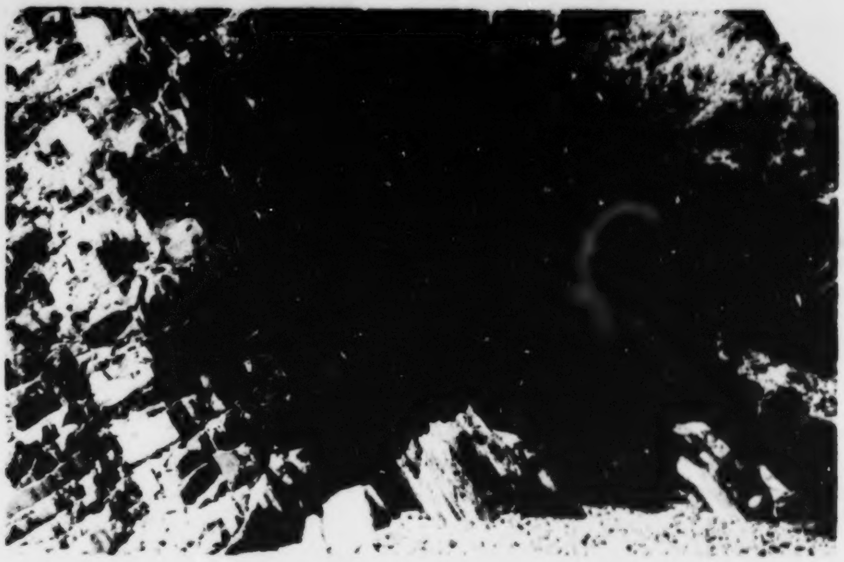


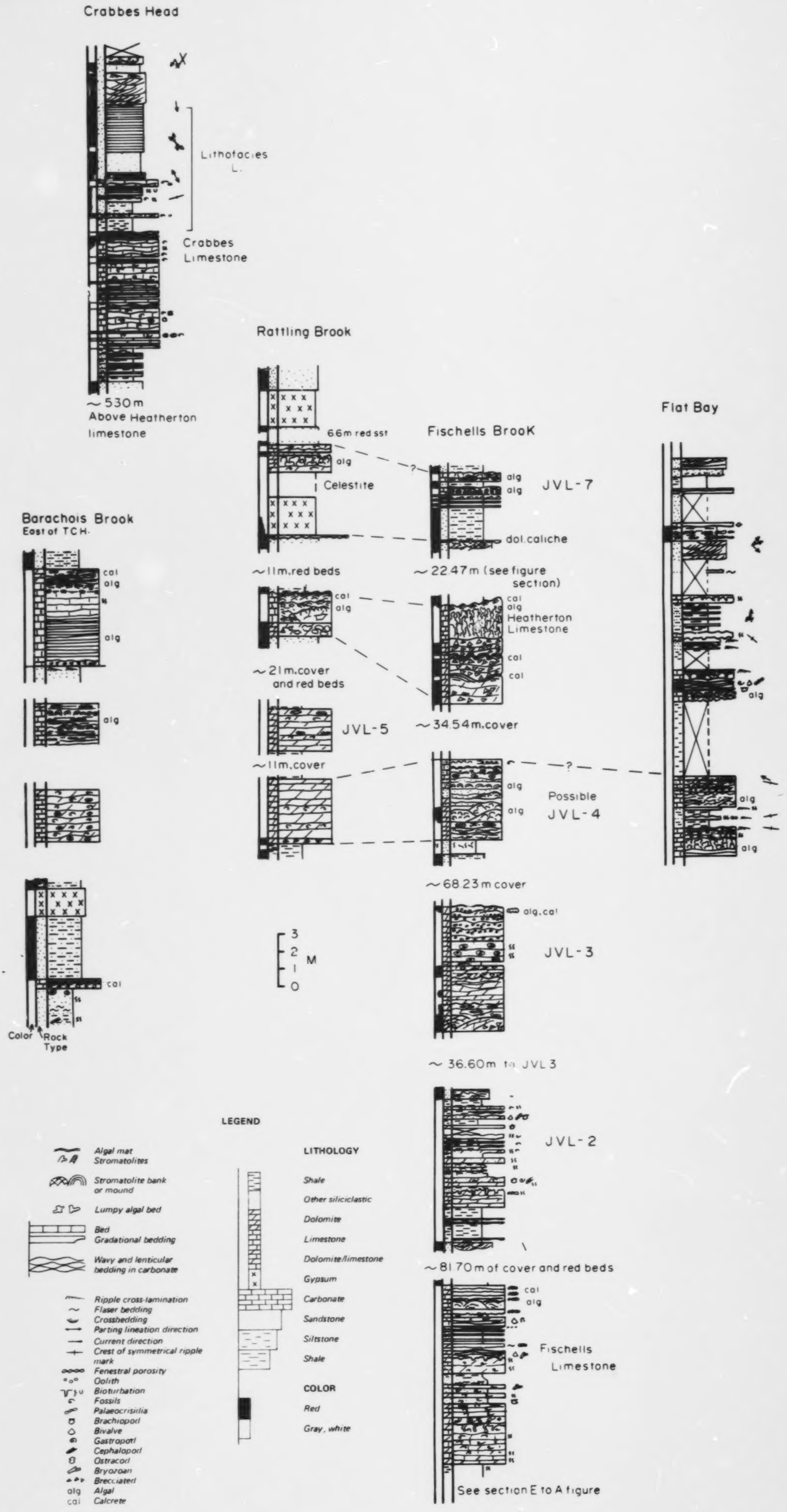
Plate 95: The Crabbes limestone, Jeffrey's Village Member, Robinsons River Formation at Crabbes Head. It consists of well bedded, dominantly gray limestone with shale partings at base and interbedded shale and limestone upwards.

lowlands and two fossiliferous dolomitic limestones on Barachois Brook are correlated with the Fischells limestone and JVL-2 of the Fischells Brook section.

Carbonate units in the Jeffrey's Village Member consist of argillaceous and silty limestones, dolomitic limestones and dolomites. They are gray, buff or reddish and are interbedded with gray mudstones and/or shales. Individual carbonate beds include mottled lime mudstones, skeletal wackestones and packstones, stromatolitic and algal carbonates, oolitic sandstones, oolitic and pisolitic limestones, and calcretes. Limestones have in some instances been replaced by red, vuggy, diagenetic dolomite. Ferruginous limestone-breccias (Codroy Breccias, Bell, 1948) occur in the basal 65 m of the member where they are associated with red siltstones (lithofacies A) and some ferruginous sandstones.

There is a gradual change of character in the carbonates through the upper Jeffrey's Village Member as seen along Fischells Brook. Dominantly subtidal carbonates rich in a near normal marine fauna near the base are replaced upward by oolitic and algal-dominated carbonates. The latter are poor in fauna and are associated locally with evaporites and oolitic limestones with radial and spherulitic ooids. These limestones are extensively dolomitized and have been modified in several units by calcretes; for example, the Heatherton limestone on Fischells Brook is composed of three beds, each consisting of red dolomite overlain by gray calcitic calcrete. Carbonate units such as the Fischells limestone, JVL-2 and JVL-3 consist of subtidal carbonates overlain by intertidal algal deposits that are capped by calcretes and redbeds. The Crabbes limestone is composed of three sequences consisting

Figure 31: Carbonate and evaporite units of the Jeffrey's Village Member, Robinsons River Formation, from various areas of the St. George's Bay lowlands. Correlation is made between Rattling Brooksand Fischells Brook and tentatively with Flat Bay section. No correlation is intended with other localities. Sections include some redbeds.


Crabbes Head
Lithofacies L.
Crabbes Limestone
~530m Above Heatherton limestone
Rattling Brook
66m red sst
alg
Celestite
~11m.red beds
cal
alg
~21m.cover and red beds
JVL-5
~11m.cover
Fischells BrooK
?
alg
alg
JVL-7
dol.caliche
~22.47m (see figure section)
cal
alg
Heatherton Limestone
cal
cal
~34.54m.cover
?
alg
alg
Possible JVL-4
~68.23m cover
alg.cal
JVL-3
~36.60m to JVL3
JVL-2
~81.70m of cover and red beds
cal
alg
Fischells Limestone
See section E to A figure
Flat Bay
alg
alg
alg
Barachois Brook
East of TCH.
cal
alg
alg
alg
cal
Color
Rock Type
3
2
1
0
M
LEGEND
Algal mat
Stromatolites
Stromatolite bank or mound
Lumpy algal bed
Bed
Gradational bedding
Wavy and lenticular bedding in carbonate
Ripple cross-lamination
Flaser bedding
Crossbedding
Parting lineation direction
Current direction
Crest of symmetrical ripple mark
Fenestral porosity
Oolith
Bioturbation
Fossils
Palaeocrisidia
Brachiopod
Bivalve
Gastropod
Cephalopod
Ostracod
Bryozoan
Brecciated
alg Algal
cal Calcrete
LITHOLOGY
Shale
Other siliciclastic
Dolomite
Limestone
Dolomite/limestone
Gypsum
Carbonate
Sandstone
Siltstone
Shale
COLOR
Red
Gray, white

of shales overlain by interbedded shales and wavy bedded limestones, and capped by wavy bedded limestones.

Several subfacies occur in the carbonates; viz. (i) burrowed lime mudstones, (ii) skeletal packstones and wackestones, (iii) algal carbonates, (iv) oolitic carbonates and sandstones, (v) calcretes, (vi) dolomites and (vii) brecciated limestones. Unlike the approach taken with the other lithofacies in the Robinsons River Formation, each of the subfacies of the marine carbonate lithofacies is described and interpreted separately.

(i) Description of burrowed lime mudstones: Lime mudstones deposited in irregular 2 to 10 cm beds are interbedded with gray calcareous mudstones and shales. They generally lie at the bases of carbonate units and are buff weathering, argillaceous and carbonaceous. They contain few fossils, but are mottled by randomly oriented, 2 mm burrows *(Helminthoida?)*. The sparse fauna consists mostly of the bivalve *Aviculopecten* and there are some algal laminae.

Moldic porosity is common and is filled by clear ferroan calcite spar or dolomite. The porosity resulted from dissolution of rhombic to needle-like crystals and of skeletal remains.

Rhombic dolomite crystals 0.02 to 0.05 mm in size are scattered through the lime mudstones.

Interpretation of burrowed lime mudstones: The subfacies was deposited in a quiet subtidal environment that hosted a sparse skeletal and soft-bodied fauna. The environment was probably near- shore shallow lagoons with elevated salinities. Moldic crystal porosity, possibly after gypsum, and fine crystalline dolomite in the lime mudstones suggest that they were affected by sabkha processes (Kinsman, 1966, 1969). The subfacies resembles facies IV wackestones of Schenk (1969, 1975) who also interpreted them as shallow lagoonal deposits.

(ii) Description of skeletal wackestones and packstones: Wackestones and packstones (Plates 98-99) consist of 10 to 40 cm thick beds of massive, buff to gray weathering carbonate interbedded with calcareous mudstones or thin gray shales. Bioturbation includes 1 to 2 cm wide burrows (Plate 96), fine *Helminthoida* and *Chondrites* (Plate 97) (Frey and Howard, 1970; Chamberlain, 1978). Scattered oncolites, 2 to 3 cm in diameter, and shell-rich layers occur in the beds. Bedding planes are mostly uneven; on some of them there are ripple marks which in places interfere with each other.

Whole brachiopod and bivalve shells are common in the shell-rich layers and borings 0.5 mm in size penetrate some brachiopod shells in the Fischells limestone.

Petrographically, the subfacies includes skeletal- and peloid-rich varieties. Crinoid detritus (Plate 98), foraminifera (Plate 99), ostracods, and peloids may each dominate the limy rocks. In other packstones/wackestones, bryozoa, brachiopods, cephalopods, gastropods, bivalves, calcispheres and rarely corals are also mixed with the previously named organic remains. Some lumps and coated grains also occur.

Foraminifera are common in the subfacies where it lies beneath algal carbonates as in JVL-4 and JVL-5 at Heatherton and JVL-4 on the south side of Fischells Brook. Those from the Crabbes limestone have been well documented by Mamet (1968) (see Table 6). In the limestones of Fischells Brook, the foraminifera are dominated by species of *Biseriammina*, but also include *Endothyra*, *Palaeotexturalia*, *Pseudoglomospira*, *Endothyranopsis*, calcispheres and encrusting *Tuberitina* (by comparison to Mamet, 1970).

Plate 96: Large burrows in dolomitic wackestone that is rich in skeletal remains, Fischells limestone, Jeffrey's Village Member, Fischells Brook. Burrows were filled by red siltstone.

The packstones and wackestones are all recrystallized to varying degrees. An originally micritic matrix is now mostly recrystallized to microspar and is partly dolomitized. In some thin sections, it contains neomorphic stellate spar (Bathurst, 1975). Shell detritus is commonly unaffected except for some micritization, but locally it has been dissolved and the molds filled by spar. Shelter and cavity porosity (Choquette and Pray, 1970) associated with fossils is usually filled by blocky calcite and some ferroan calcite spar.

In carbonate units near "round valley" in the Codroy lowlands, the subfacies is silty and darkened by carbonaceous matter including algal laminae. The latter bind the matrix and encompass the larger fossils to form oncolites (Plate 100). Skeletal grains are predominantly ostracods, but include some crinoids, monocellular encrusting foraminifera, bryozoans, bivalves, brachiopods, branching tubular corals and cephalopods. In one unit of dolomitic packstone, the skeletal components are mostly crinoids and bryozoans. Shell material is selectively replaced by clear spar. Layered, acicular, radial and structureless brown micritic cements encrust skeletal remains (Plate 101). Algal laminations bind skeletal material and lime mud to form small heads 0.5 to 2 cm in width on the outsides of shells in the carbonates in the Codroy lowlands. The oncolitic structure is unevenly developed around the shell and includes interlaminar porosity that is now filled by clear spar. Prismatic authigenic quartz is abundant in the cement (Plate 101) and the algal structures.

Interpretation of skeletal wackestones and packstones: The lack of current structures, the interbedded shales, abundance of bioturbation and

Plate 97: *Chondrites* in dolomitic lime mudstones, overlain by brachiopod-rich layer in JVL-2 limestone, Fischells Brook. Upper part of Jeffrey's Village Member, Robinsons River Formation.

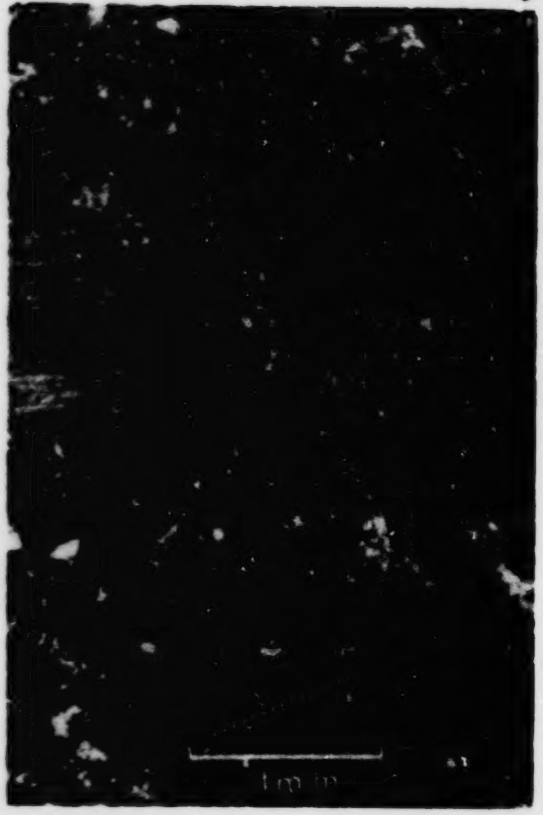


Plate 98: Crinoidal wackestone composed of complete and fragmented crinoid ossicles, Crabbes limestone, Jeffrey's Village Member, south of mouth of Crabbes River.

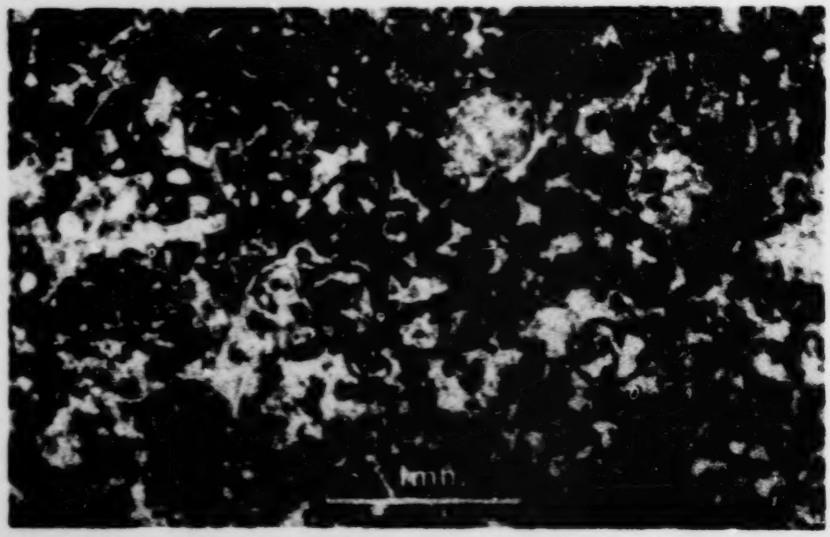
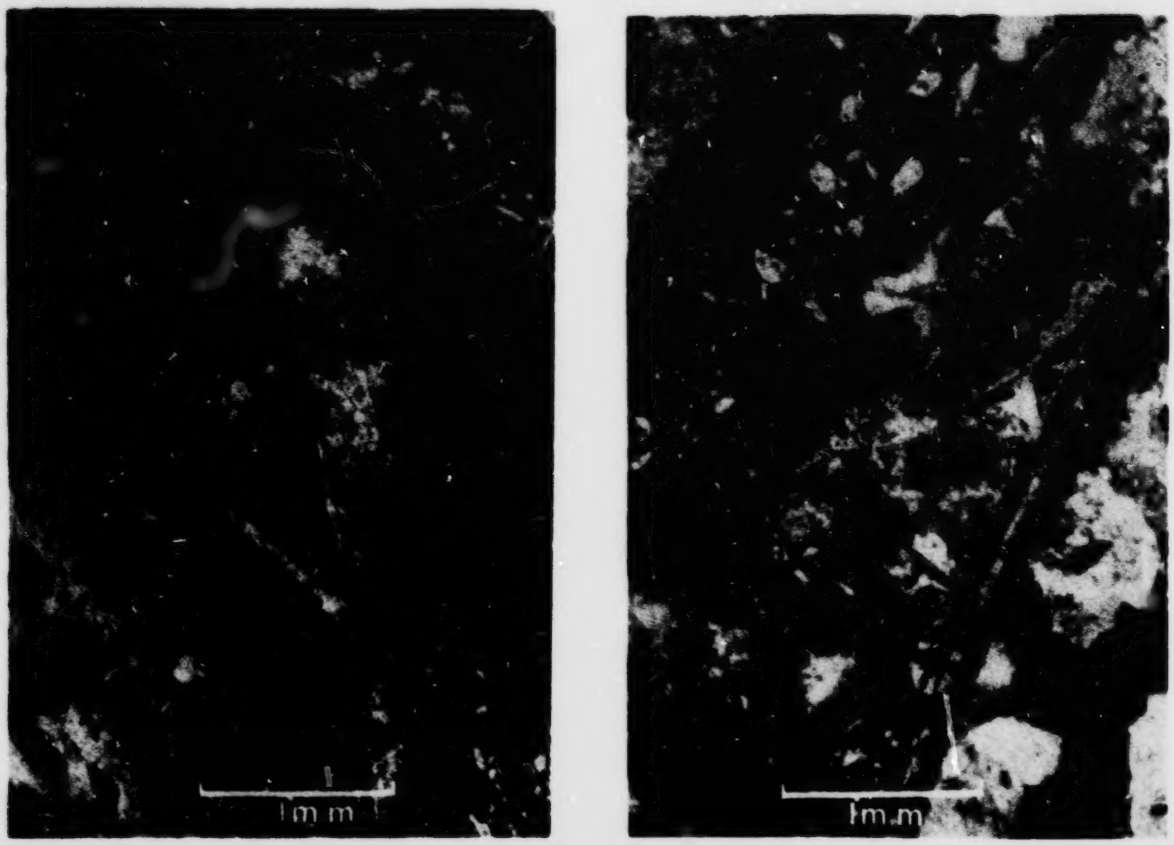


Plate 99: Skeletal-peloid packstone composed of foraminifera, crinoid ossicles, ostracods and calcispheres. Limestone in Shallop Cove, Flat Bay.



Plates 100 to 101: Photomicrographs of areas of a goniatite shell enclosed in a carbonaceous dolomitic wackestone, "round valley", Codroy lowlands. Algae initially bound the outer wall of the shell, sealing over fractured shell (Plate 100). Crinoid grains were enclosed by this algal coat. Within the goniatite, septa were coated by a fine, fibrous cement (Plate 101) which was also precipitated in and around whole ostracods that had entered the chambers. Chambers were later filled by blocky spar. Original shell replaced by clear neomorphic spar; structure visible (Plate 100). Authigenic quartz occurs in plate 101.

general poor sorting of these carbonates suggests that they were laid down in a generally quiet subtidal environment. The diversity of fauna and other allochems suggests a number of ecological niches. Packstones dominated by crinoids or a mixed crinoid-brachiopod-bryozoan fauna perhaps accumulated on subtidal shoals that were influenced by current action and had near normal salinities (Johnson, 1971; Heckel, 1972). Foraminiferid-peloid packstones, however, suggest quieter, more sheltered areas. The foraminifera are dominated by the form *Biseriammina* which, according to Mamet (1970), is principally found in oolite bank or hypersaline lagoon settings. The subsidiary protozoa are more typical of the lagoonal setting (Mamet, 1970) and the abundance of peloids and lack of ooids in the packstones suggest quiet lagoonal conditions. *Chondrites* burrows are most common in shallow, subtidal

Plate 102: Heatherton limestone, Jeffrey's Village Member, Fischells Brook, composed of gray limestone and red dolomite. The upper gray limestone bed consists of calcrete-modified stromatolites. This overlies a lower, irregular gray calcrete (arrow) that caps an irregular bed of red dolomite (r).

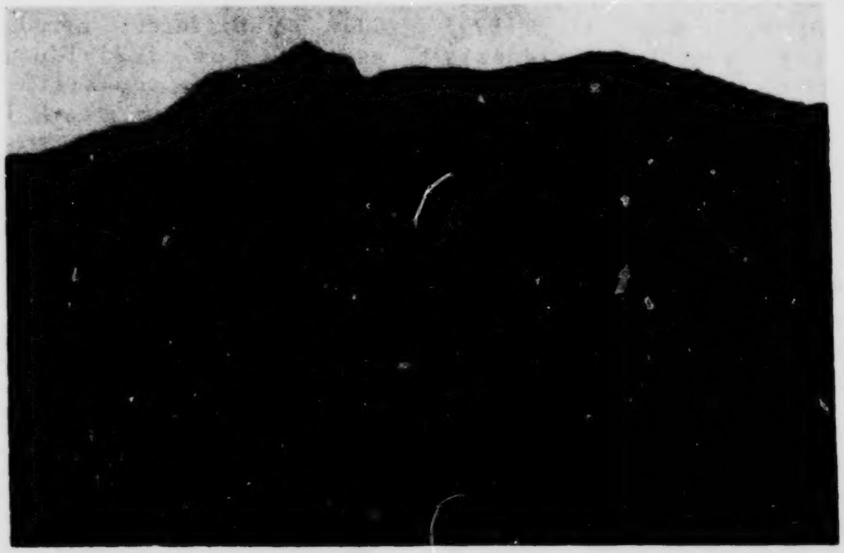


Plate 103: Heatherton limestone, Jeffrey's Village Member at Rattling Brook, formed of large mounds built by inclined, asymmetric algal heads and columns.

marine environments, but may also occur in nearshore or central areas of lagoons (Chamberlain, 1978). The rock types encompass Schenk's (1969, 1975) facies I wackestones and facies V biosparites (grainstones) which were interpreted as deposits of inner shelf and reef environments.

The facies in the Codroy lowlands was supplied with more extrabasinal silt and mud than the carbonates in the St. George's Bay area. The fauna is quite diverse but is dominated mostly by ostracods. This suggests that it was probably deposited near shore with most skeletal grains carried into the quiet muddy environment from adjacent carbonate-rich areas. Oncolitic algal growths on shell fragments, leaching of shell material, and presence of multiple cements suggest a complex depositional history for some of the "round valley" carbonates. This history included precipitation of fibrous subtidal marine cements (Taylor and Illing, 1969; Friedman et al., 1974), binding of skeletal grains by subtidal algae (Scoffin, 1970; Neumann et al., 1970) and freshwater vadose diagenesis (Longman, 1980).

(iii) Description of algal carbonates: Small algal structures, a few centimetres in size, are found as oncolites and small columnar and domal heads in the mudstones and packstones. However, larger algal structures fill complete beds in various limestone units throughout the Jeffrey's Village Member. The deposits are of two types:

a. banks and beds of well developed columnar and domal stromatolites, and flat laminated algal mat composed of buff weathering, dolomitic, silty and argillaceous micrite;

b. beds of very irregular lumps of dark brown, vuggy dolomite that possess no structure characteristic of laminated, stromatolite buildups, but do include textures of codiacean algae and serpulid worms.

Stromatolites of the first type are best developed in the Heatherton limestone (Plates 102-103) and in a deposit on Highlands River (Figure 27; Plate 104). Thin developments of stromatolites also occur in several beds, 10 to 35 cm thick, 4 km east of the Trans Canada Highway on Barachois Brook.

The stromatolites of the Heatherton limestone are 1.8 m thick at Rattling Brook but increase to 3 m at Fischells Brook. At Rattling Brook large domal mounds 20 to 60 cm high and up to 4.5 m across occur. The mounds appear to overlap each other and the mound surface is fashioned by individual, asymmetric, inverted cone-shaped heads; these are 10 to 20 cm high and 15 cm in diameter, and form caps to tilted columnar stromatolites within the beds (Plate 103). All the heads have a slight elongation and their steep sides face 320°, 332° and 005° on different mounds. In cross sections of individual beds, the stromatolites consist of columnar structures that lean in a similar northward direction. Traced southward along the Rattling Brook exposure, the heads become rounded. Traced northward to Fischells Brook, they pass into vertically-elongate, smooth, lumpy heads that have been modified by calcrete development. The algal limestones are also extensively replaced by red dolomite.

Microscopically, the heads at Rattling Brook are composed of carbonate that resembles dark, mottled peloid packstone and locally contains ostracod detritus. The peloids, which are 0.05 mm in size, appear to have broken down to micrite locally or pervasively. Some peloids are coated by a fine, radiating, acicular carbonate layer, and fenestral porosity is closed by blocky calcite and ferroan calcite spar.

Plate 104: Inclined, curved, columnar stromatolites of the Jeffrey's Village Member, in two beds that formed an algal bank above oolitic, skeletal packstones on Highlands River, near Loch Lomond. The stromatolites are overlain by gray shales and sandstones of lithofacies M.

Plate 105: Close-up of columnar stromatolites on Highlands River.

Plate 106: Lumpy, black algal carbonate of lithofacies R, Jeffrey's Village Member, Robinsons River Formation, at Rattling Brook. Bed overlies celestite and gypsum beds that are concealed below beach gravel.

The algal deposits on the Highlands River consist of two beds of columnar stromatolites, 45 and 58 cm thick (Plates 104 and 105). The stromatolites overlie shales and dolomitic, skeletal and oolitic wackestones and packstones. The columns, which are 5 to 10 cm in diameter, show marked changes of tilt direction between the two beds. The stromatolites are built of buff and gray colored laminae that resemble smooth mat in the lower parts of heads and broken smooth mat at the top of heads (Logan et al., 1974); the centres of some heads are locally recrystallized to unstructured microspar. The lamination is formed by mottled micrite alternating with sparry micrite rich in fenestral porosity. Ooids are locally bound within the lamination. Narrow, circular to bird's-eye shaped fenestra are filled by coarse, blocky spar (0.5 mm size), which coarsens inward from pore margins. Some of the larger pores sheltered ostracods. Lime mud, ooids, skeletal fragments and flakes derived from the broken smooth mat of the algal head top fill interstices between the heads.

Flat laminated stromatolitic carbonates, 30 cm thick, overlie irregular lumpy algal beds at Flat Bay. They are also the most common stromatolite type along Barachois Brook, where they occur only a few hundred metres from the Crabbes Brook fault. At this locality, they are 10 to 260 cm thick and are associated with 10 to 35 cm beds of SH-C stromatolites, bioturbated lime mudstones and some calcrete (Figure 31). The flat stromatolites are composed of either microcrystalline dolomite (0.03 mm grain size), with partly dolomitized micrite laminae, or dense, peloid packstones similar to those described in the Heatherton limestone; both contain irregular fenestral porosity (Logan, 1974). In algal mats composed of peloids, the lamination is picked out by

Plate 107: Photomicrograph of small clots of codiacean algae that form lumpy algal carbonates at Rattling Brook (Plate 106). Spaces between lumps are filled by elongate, calcite crystals resembling the lath-like textures of calcitized gypsum (Shearman and Fuller, 1969).

size sorting of peloids, and by concentration of silt-sized quartz and mica grains. The peloids, which are mostly 0.03 mm and rarely up to 0.4 mm in diameter, consist of dark cryptocrystalline micrite with rather diffuse boundaries. Clear microspar fills the interpeloid spaces.

Lumpy algal carbonates (Plate 106), composed of black dolomite, represent the second type of algal carbonate deposit in the lithofacies. At Rattling Brook and Flat Bay they occur in the Jeffrey's Village Member where they form beds up to 92 cm thick (Figure 31). The beds are composed of brecciated carbonate at the base and nodular to cavernous dolomite upward. Microscopically, the unstructured dolomites are composed of small lumps, 1.5 to 3.5 mm in size, separated by narrow channels and irregular porosity. The lumps are formed of dark cryptocrystalline micrite permeated by 0.03 mm diameter, spar-filled tubules (Plate 107), that are similar to codiacean algae or *Girvanella* (Bathurst, 1975; Scholle, 1978). The lump structure gives way to areas of patchy and mottled micrite associated with a spar-filled, ramose pore system (0.15 mm wide). The micrite is replaced by patches of brown, fine, fibrous dolomite.

The lumpy carbonates contain worm tubes which are 0.3 mm in diameter (Plate 108) and have a fine fibrous wall structure similar to *Serpula* (cf. Johnson, 1971). Radial, acicular cement (Bathurst, 1975) fills the tubes, but appears to overprint an earlier, fibrous cement attached to the tube walls. Remaining porosity in the worm tubes and within the algal lumps in general is filled by blocky spar. Broader channels between the algal lumps are locally crossed by 3 mm long, 0.08 to 0.09 mm wide lath-like calcite crystals (Plate 107).

Interpretation of the algal carbonates: The stromatolites were deposited in low to high energy intertidal settings that included banks and algal flats. Banks of large mounds and columnar stromatolites formed important buildups in JVL-4 and JVL-6 of the Fischells Brook section. The buildups, with their asymmetric stromatolite heads (Heatherton limestone at Rattling Brook) and inclined columns (limestone, Highlands River), suggest high energy settings. Unfortunately, the areal distribution of the stromatolite deposits and their lateral relationships to other carbonate subfacies are unknown. In most sections, the stromatolites lie above subtidal carbonates and are capped by laminated algal mat, calcrete or redbeds. This

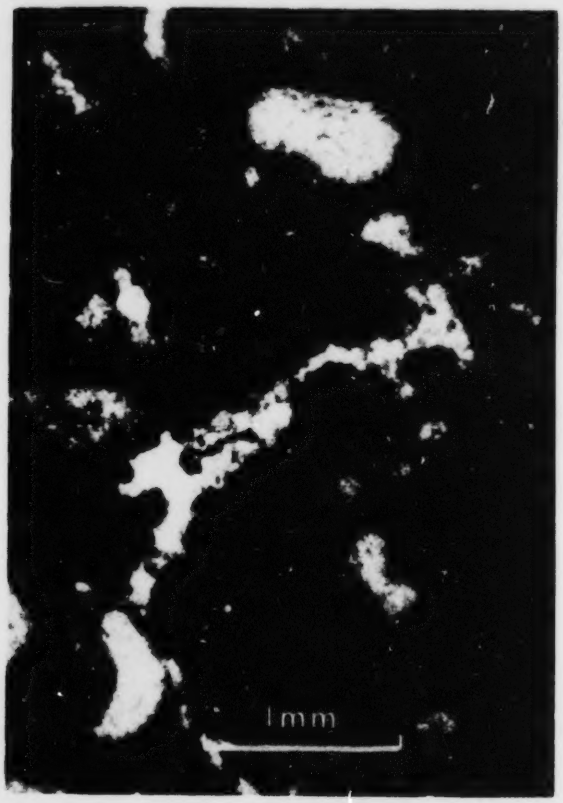


Plate 108: Worm tubes lined by fine acicular druse and by mosaic spar, associated with dark mottled peloid packstone in the lumpy algal carbonates (Plate 106) at Rattling Brook. Base is 1 mm long.

may indicate that they were attached to prograding shorelines similar to Shark Bay, Australia (Logan et al., 1974), and that the algal heads and mounds formed on exposed high energy headlands, where they were fashioned by wave action.

A different environment, however, is proposed for the Highlands River deposit which is associated with the subtidal, lagoonal shales and sandstones of lithofacies K. In this case an algal bank may have formed a barrier behind which a lagoon formed. The growth of inclined columnar stromatolites in the deposit could then have been controlled by tidal currents (Hoffman, 1967, 1976; Logan et al., 1974; Playford and Cockbain, 1976) that flowed in and out of the lagoon, perhaps along tidal channels.

Flat algal mats occur at the tops of some algal banks where they are intercalated with stromatolite heads. They also cap the oolitic and oncolitic deposits of JVL-3 and are common in the most easterly carbonates of the Jeffrey's Village Member along Barachois Brook. They are interpreted as the deposits of sheltered, low lying areas of tidal flats (Kendall and Skipwith, 1968, 1969; Logan et al., 1974).

The lumpy algal carbonates were built of blue-green algae, resembling modern codiacean algae and the fossil algae *Girvanella*. Curved worm tubes with wall structures similar to *Serpula* (Johnson, 1971) were also important in the construction of the lumps. Fine, radiating, acicular cement within the worm tubes may be similar to cements of the shallow subtidal deposits of the Persian Gulf (Taylor and Illing 1969; Shinn, 1969) or those found in modern reefs (Land and Goreau, 1970; Friedman et al., 1974; James et al., 1976). However, the lath-like calcite crystals between the lumps resemble the felted crystal fabrics of ancient and modern calcitized sulfate evaporites (Shearman and Fuller, 1969). Since the lumpy algal beds immediately overlie gypsum and celestite beds, it is probable the carbonates and evaporites were deposited in a shallow, hypersaline, lagoonal setting.

(iv) Description of oolitic carbonates and sandstones: This subfacies consists of grainstones and calcareous sandstones that are oolitic or both oolitic and intraclastic. They occur in beds, up to 1.6 m thick, in limestones JVL-3 and 4 of the Fischells Brook sections and in limestones at Muddy Hole and Flat Bay (Plate 109). Dolomitized oolitic limestones are associated with stromatolites along Barachois Brook.

Plate 109: Oolitic limestone in carbonate unit at base of Flat Bay section, Jeffrey's Village Member, Robinsons River Formation (Figure 31). It is gray, displays lamination, wavy lamination and ripple cross-lamination and is rich in lime intraclasts at base.

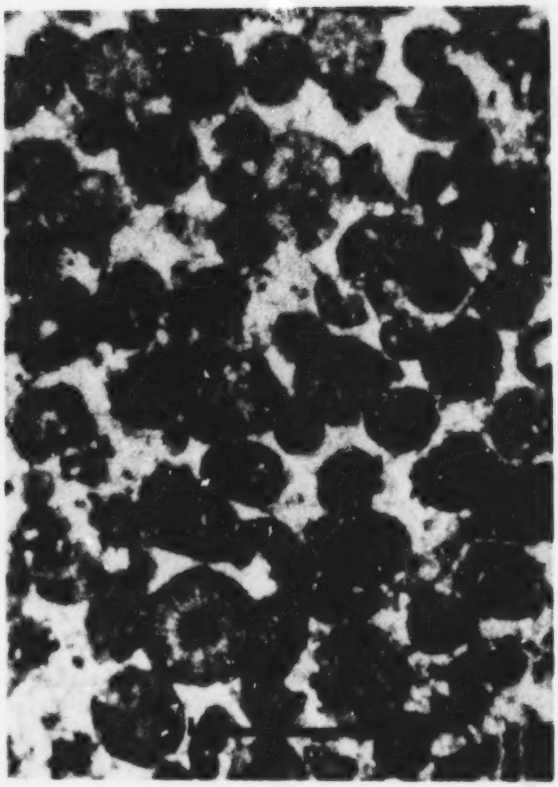


Plate 110: Oolitic grainstone from unit in Flat Bay (Plate 109) composed of radial concentric ooids cemented by sparry calcite. Grains have sutured contacts; broken ooids and several spherulites are present. Plane light.

The oolitic grainstones are intercalated with oolitic sandstones on a centimetre scale. They display wavy and flaser bedding (Reineck and Wunderlich, 1968), lamination and cross-lamination (Plate 109), and have ripple-marked bedding surfaces. The oolitic-intraclastic sandstones are generally laminated.

The oolitic grainstones (Plate 110) consist of brown, well sorted, generally well rounded, fine to medium grained ooids, cemented by clear calcite spar. Sutured, iron-stained grain contacts occur between ooids. Internally, the ooids have a radial-concentric fabric, although some grains have a coarser, spherulitic, radiating texture (Plate 111). Fusion of incomplete or perhaps broken grains is common and it is not unusual to see grains with two or more centres of radial growth (Plate 111). Fine, clear, spar-filled lines are abundant in some ooids, perhaps indicating healing of slightly broken grains. Nuclei are predominantly micrite, but also consist of sparry calcite, terrigenous sand grains and molluscan, algal or bryozoan fragments. Uncoated quartz grains, some peloids and a few bryozoa fragments are scattered in the grainstones.

Plate 111: Close-up of radial ooids from oolitic grainstone of plate 110 showing multiple growth and fine spar-filled rays that are possibly healed microfractures. Plane light.

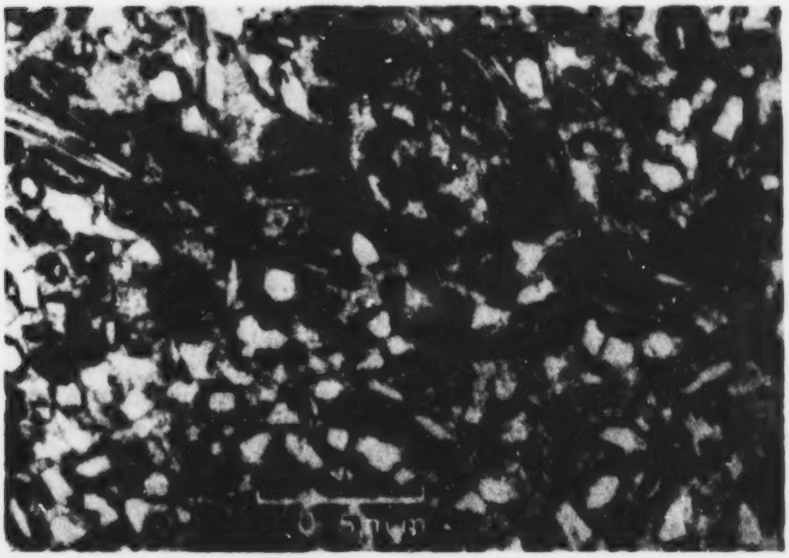


Plate 112: Coated sand grains in a calcareous, very fine sandstone from carbonate unit, Jeffrey's Village Member, at Flat Bay. Note shredded micas (arrow) and the rare ooid. Plane light.

The oolitic sandstones are composed of fine grained ooids mixed with equal quantities of quartz and mica, cemented by clear spar. In the sandstone, some of the sand grains are completely coated with micrite (Plate 112), while in others sand grains protrude through the ooid laminae. Micas that have not acted as ooid nuclei have been shredded and enlarged to about ten times their original size by precipitation of microspar cement between cleavage plates.

The laminated intraclastic sandstones are composed of lithoclasts, mollusc and ostracod shells, coated sand and skeletal grains, and a few poorly shaped and incomplete ooids. The lithoclasts, which are up to 6.8 mm long and 0.18 mm wide, are composed of dark, carbonaceous, dense micrite similar to the stromatolitic carbonates. The lamination is produced by the alternation of poorly sorted, intraclastic and skeletal fine sandstones with better sorted, very fine sandstones that have a sparry cement.

Interpretation of oolite carbonates and sandstones: The presence of well sorted, spar-cemented, oolitic grainstones and oolitic sandstones suggests that high energy shoals, tidal deltas or beaches occurred in the marine environment. Terrigenous sands transported into the high energy settings became nuclei for the ooids. sand grains together with mature ooids suggest nearshore terrigenous sand was continually supplied to the ooid shoals. Ooids swept from the shoal areas were mixed with platy lithoclasts that were derived by erosion of an intertidal algal mat in adjacent quiet lagoon or tidal flat areas. Where oolitic sands became stabilized, they were subject to cementation.

The ooids have a well developed radial fabric and include coarser spherulitic grains. They are typical of ooids that form in hypersaline environments such as Great Salt Lake (Sandberg, 1975; Halley, 1977), the Persian Gulf (Purser and Loreau, 1973) and saline pools of the Gulf of Aqaba (Friedman et al., 1973). Nonetheless, Sandberg (1975) has cautioned against using them as a diagnostic indicator. According to Halley (1977) however, ooids formed in hypersaline environments are generally weak and easily broken by agitation. The frequent occurrence of hairline fractures in ooids and of fragmented and healed broken ooids in the Jeffrey's Village carbonates indeed suggest they were brittle and supports a hypersaline setting. The facies is equivalent to facies III oosparites of Schenk (1969, 1975), who also interpreted them as ooid shoals.

(v) Description of calcrete: This subfacies is formed of gray and red, very finely laminated, massive, nodular and lumpy, dense micrites and dolomites. They replace algal limestones and skeletal packstones particularly near the top of carbonate units.

The most spectacular example of calcrete is developed in the Heatherton limestone on Fischells Brook. Here the calcrete has replaced the original stromatolite heads so that they now consist of vertically elongate lumps which have smooth, rounded, protuberant forms and a fine curvilinear striation on outer surfaces. The internal structure of the heads can be seen in slabbed samples and some planed-off outcrops (Plate 113). It consists of a core of peloid-micrite with laminar and/or irregular fenestral porosity (Logan, 1974), surrounded by an outer dense, finely laminated, cryptocrystalline limestone cap. Laminar structure decreases into the stromatolite heads and the inner surface of the laminar cap is undulose to micronodular.

In the exposures of the Heatherton limestone on the north bank of Fischells Brook, the lumpy calcretized stromatolite bed overlies two beds of red dolomite that are separated by laminar and structureless micritic calcrete.

Plate 113: Red, laminar calcrete surrounding coarse fenestral core in calcrete-modified algal heads of the Heatherton limestone, Jeffrey's Village Member, at Rattling Brook. Gray carbonate infills between heads.

Plate 114: Nodular calcrete capping a fossiliferous limestone and calcareous sandstone of the Jeffrey's Village Member on the North Branch River, 3 km downstream of the main road bridge, Trans Canada Highway.

Red laminated calcrete occurs in the upper beds of the Crabbes limestone at Robinsons Head. The laminae may be poorly developed or may form fine, flat, dense layers up to 1 cm thick. Nodules consisting of laminar structure around a porous, hematitic dolomite core also occur. The laminar structure of the nodules is composed of very fine dolomite that is smooth to microcrinkly. Locally, laminated structures resembling stromatolite hemispheroids project downward into the packstone beneath the nodules. Within the nodules, hematite masks the fine dolomite matrix, but even where iron content is low, the matrix is clouded and dense. Skeletal remains were either obliterated, or leached and replaced by mosaic spar within the nodules. A few ostracod shells have been preserved in one corner of a large nodule. Irregular porosity and rhombic to lath-like molds that have the shapes of gypsum crystals are common within the nodules. Examination of the lower side of the nodules in reflected light reveals incipient laminar growth, faint iron coloration, and gradual decrease of the clouded appearance down into the underlying packstone.

Nodular calcrete, with oncolites and pisolites (Steel, 1973), occurs in a unit along the North Branch of the Grand Codroy River near "round valley" (Plate 114). It has developed on the top of both dolomitized, burrowed, crinoid-bryozoa wackestone and quartzose sandstones.

Interpretation of calcrete: The structures and texture of these microcrystalline limestones and dolomites are consistent with those of calcretes. Laminar and porous-laminar structure is common in modern (Multer and Hoffmeister, 1968; James, 1972; Read, 1974, 1976; Robbin and Stipp, 1979) and ancient (Bernoulli and Wagner, 1971; Wall et al., 1975) calcretes. Pisoliths and nodular structures in some of the deposits are similar to structures found in modern and ancient caliches (Gile et al., 1966; Reeves, 1970; Steel, 1973). Their stratigraphic position, at the top or in upper beds of carbonate units that are overlain by redbeds, also supports the interpretation of these rocks as calcretes.

Laminar calcretes are indicative of soil development (Multer and Hoffmeister, 1968) in semiarid climates or in climates where high humidity alternates with high evaporation rates (Read, 1976). They form generally by leaching of carbonate and precipitation of cryptocrystalline calcite crusts (Read, 1976) in the vadose zone. In the carbonates of the Jeffrey's Village Member, the laminar carbonates range from surficial crusts or rinds on top of stromatolite heads or exposed packstones, to well developed calcretes that modified greatly the original stromatolitic limestones. The diffuse, incipient diagenesis beneath the laminar and laminar-nodular crusts in the packstone of the Crabbes limestone indicates the calcrete developed by downward percolating vadose waters. The laminar structure advanced upward (Multer and Hoffmeister, 1968) after the substrate was plugged (Read, 1976).

Seawater flooding or salt-spray wetting of exposed limestone surfaces may have produced the dolomitic calcretes of the Crabbes limestone. Here hypersaline vadose diagenesis (Scholle and Kinsman, 1974) affected the exposed limestones. The restriction of the gypsum molds to the nodules in the dolomite crusts may reflect the development of a saline microenvironment within the nodules, and so indicate early plugging of the profile. Dissolution of both skeletal grains and gypsum in the packstones suggests later dissolution by freshwater.

The alternation of brecciated red dolomite, capped by laminar, gray calcitic calcrete in the Heatherton limestone suggests a complex history of carbonate deposition and diagenesis for this unit.

(vi) Description of dolomites: Dolomitization of the carbonate units in the Jeffrey's Village Member is variable. It has formed small dolomite crystals scattered through many of the limestones, while in other cases the original carbonate has been completely replaced by 0.05 to 0.2 mm crystalline dolomite. The most spectacular dolomitization occurs in algal limestones of the St. George's Bay area where limestones gradually give way downward into cavernous, rubbly and red colored dolomite. The red dolomite is capped by laminar calcitic calcrete in the Heatherton limestone.

Interpretation of dolomitization: Dolomite is widespread in Windsor Group carbonates of Nova Scotia (Schenk, 1969) and is believed to have formed relatively early in their history. Some of this dolomitization has been already ascribed to sabkha diagenesis (see lime mudstones). Much of the advanced dolomitization, however, may have occurred by mixing of fresh and saline solutions in the shallow subsurface (Badiozamani, 1973) rather than in the sabkha environment. This is suggested by the downward increase in dolomitization of such beds as the Heatherton limestone. It is also supported by the general lack of evaporite mineral growth in and associated with the limestones.

(vii) Description of limestone breccias: Several limestone-breccia beds occur in the basal 56 m of the Jeffrey's Village Member, along the coastal section near Woodville, Codroy lowlands. They are 25 to 322 cm thick and include the Codroy Breccia (Bell, 1948). They are associated with red siltstones and ferruginous sandstones. The breccias also occur at Ship Cove, on the south side of round valley, and are known from float in synclines that are cored by Codroy strata in the Anguille Mountains.

The limestone-breccias from Woodville (Plate 115) consist mostly of ungraded beds, 10 to 40 cm thick. Some thin beds, however, are graded, while others consist of alternating breccia (10 to 29 cm) and ferruginous sandstone (4 to 14 cm). Crude crossbedding with foresets graded from breccia to sandstone occur in one bed in the 'Codroy Breccia'. The bases of breccias either are sharp upon siltstone or gradationally overlie it. The breccias contain angular lithoclasts, 1 to 3 cm in size, set in a matrix of yellow weathering, ferruginous, silty micrite (Plate 116). Lithologies of breccia clasts include lime mudstones, algal carbonates, skeletal packstones, peloidal wackestones and oolitic grainstones (Plates 117-122). The major skeletal grains are crinoids, some of which are hematized; bryozoa, which may include ramose and tabular types; ostracods; and some bivalve and gastropod debris. Crinoids (Plate 117) also occur as individual grains with syntaxial crystal overgrowths. Individual ooids are scattered in the breccias.

Algal carbonate lithoclasts have structures similar to the codiacean algae of the lumpy algal carbonates (Plate 122). Serpulid worm tubes (Plate 122), filled by radiating fibrous cements, are also common in lime mudstone or peloidal packstone fragments; brown radiating fibrous calcite that appears to have replaced lime mudstone also occurs in the serpulid lime mudstone fragments. There are also many pisoliths (Plate 117) and angular lithoclasts (Plate 120), with both radial and concentric layering separated by local discontinuities.

The breccias in the Anguille Mountains are composed mostly of fragments of lime mud, and serpulid lime mudstone; minor components are grains of oolitic grainstone, crinoid ossicles and pisoliths. The proportion of grains to matrix in the breccias is greater than at Codroy and there is little cementation. Very coarse grained sandstone partings occur in the breccias.

Plate 115: Interbedded limestone-breccias (lithofacies R) and red siltstones above main 'Codroy Breccia', base of Jeffrey's Village Member, Robinsons River Formation, Woodville, Codroy lowlands.

Plate 116: Close-up of limestone-breccia of the 'Codroy Breccia' Jeffrey's Village Member. Dark limestone fragments are set in a yellow, ferruginous, argillaceous carbonate matrix.

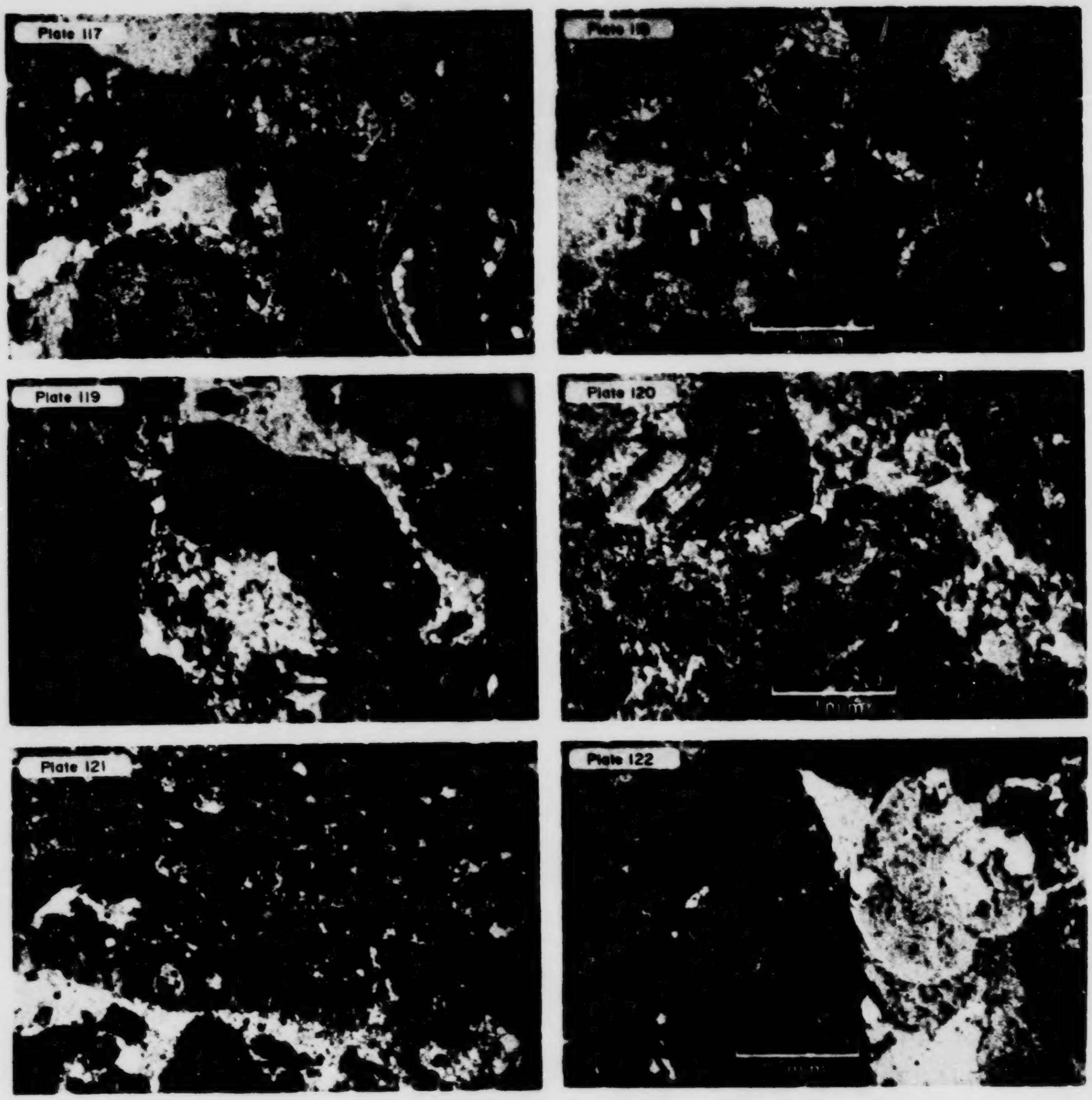


Plate 117
Plate 118
Plate 119
Plate 120
1mm
Plate 121
Plate 122

Plates 117 to 122: Photomicrographs of selected lithoclasts of the 'Codroy Breccia'. Fragments include crinoid ossicles (Plate 117), pisoliths (Plates 117-118), ooids and oolitic packstone (Plates 118-119), lithoclasts of brown fibrous carbonate replacing micrite (Plate 120), lithoclasts of radial-concentric layering (Plate 120), encrusting bryozoa and algal mat (Plate 121) and codiacean algae and worm tubes (Plate 122). Scattered quartz grains are also present, and all fragments are cemented by clear spar.

The matrix and clasts in all the breccias are commonly stained with limonite and hematite. Some of the skeletal grains and a few of the larger intraclasts, as well as parts of the matrix, have been completely replaced by hematite. Sparry calcite has cemented fracture and inter- and intra-particle porosity.

The ferruginous sandstones are rarely thicker than 50 cm. They are generally poorly bedded and overlie the breccias either sharply or gradationally. Rare fossil fragments occur in the sandstones. Structureless red siltstones occur either in 29 to 460 cm thick beds that overlie the sandstones in the upper part of the section or lie as poorly defined layers within the main "Codroy breccias".

Interpretation of the limestone--breccias: The genesis of the subfacies is clearly a complex problem. The breccias are derived from marine carbonates, but there is no evidence of interbedded evaporites. They are not, therefore, collapse breccias formed after dissolution of evaporites. In the Anguille Mountains the clasts are dominantly of one type, eg. lime mudstone, but in the Codroy area they include sediments from a wide variety of marine carbonate environments. The clast variety probably reflects the local variety of original rock types, and the contrast between the two areas is interpreted as an indication of minimal transport. Fibrous cement in lime mudstones and serpulid worm tubes indicates marine diagenesis before brecciation. The ooliths and clasts with both radial and concentric laminations resemble cave pisoliths (Bathurst, 1975) and may indicate that brecciation was also preceded by freshwater vadose diagenesis. The ferruginous red siltstones that are associated with the breccias are similar to "terra rossa" deposits, and supports a karstic origin for the breccias. Locally, marine or fluvial currents may have caused reworking to produce a greater degree of sorting.

Wall et al. (1975) described limestones in the Carboniferous of Kentucky that are interbedded with fine redbeds and have a similar history of karsting, brecciation and soil development.

(S) EVAPORITE LITHOFACIES

Description of lithofacies S: Gypsum, anhydrite, halite, potassic salts and celestite occur in the Jeffrey's Village Member in the St. George's Bay area. Salt deposits probably also underlie the area of Little Codroy River near St. Andrew's in the Codroy lowlands (Hooker Chemical Corporation, 1971).

Gypsum occurs at Plaster Cove and in association with limestones and celestite at Rattling Brook, near Heatherton. These two deposits form gypsum zones C and D of Bell (1948) respectively, but unlike the basal zones A and B of the Codroy Road Formation, appear to be restricted in distribution.

Zone C gypsum at Plaster Cove is 45 m thick (Bell, 1948). It consists of coarsely crystalline, selenitic gypsum that is overlain by red siltstones. The gypsum overlies laminated and cross-laminated green sandstones, and laminated and massive gray siltstones.

Zone D gypsum occurs in two beds, each 2 to 3 m thick, on the coast at Rattling Brook. The beds are intercalated with algal dolomites and limestones, red sandstones and siltstones, and a bed of celestite (section K, Bell, 1948); the sandstones are fine to medium grained, well sorted, and crossbedded and laminated. The gypsum is white to reddish, finely crystalline and encloses numerous, floating 1 cm gypsum crystals (Plate 123). Thin beds of gypsum with red shale partings and streaks occur at the base and are overlain by massive gypsum. The massive bed contains radiating chevron structures 10 to 20 cm in diameter (Plate 124) that resemble deformation structures described from the tectonized

Plate 123: Layered white and red gypsum, rich in gypsum porphyroblasts. Lithofacies S, Jeffrey's Village Member, Robinsons River Formation, Rattling Brook.

Plate 124: Close up of radiating chevron-like structure in gypsum above that shown in Plate 123, Rattling Brook.

Messinian evaporites of Sicily and the gypsum deposits of Nova Scotia (Schreiber et al., 1976). A smooth to mammilated crust of dolomite caliche, 2 cm thick, caps the red sandstones that underlie the gypsum.

Dappled gray and white celestite occurs in a bed 45 cm thick at Rattling Brook (Figure 31). It is variously finely and coarsely crystalline with intergranular porosity, and the textures resemble those of intensely dolomitized carbonates described by Beales and Oldershaw (1969). Fine detrital mica and quartz and some fine rhombic dolomite occur in the celestite.

The halite deposits of the formation are known only from exploration drilling at three localities near Fischells Brook, St. Fintan's and Robinsons (Hooker Chemical Corporation, 1968a, 1972, 1973). Salt is also suggested by a number of low gravity anomalies in other areas of the subbasin (Figures 33 and 46) (Hooker Chemical Corporation, 1968b, 1971). Halite is associated with anhydrite and gypsum and is interbedded with fine grained siliciclastics. Sylvite, carnallite and polyhalite also occur with the halite. Well bedded deposits occur at St. Fintan's and Robinsons where the salt sections are 120 and 180 m thick respectively; a thinner sequence of salt (54+ m thick) also occurs beneath the main salts in the Robinsons drill hole. The salts are thicker (390 m+) and cleaner at Fischells Brook, and this may reflect a longer period of salt accumulation although the thickness at this locality may well have been increased by salt tectonics.

Salt beds in the St. Fintan's and Robinsons deposits are never greater than 3 to 4 m thick. They are white, neutral, gray, pink or red in color and some units are color-banded. Clean salt with less than 5% impurities and 'dirty' salt both occur. The potassic salts are contained at several levels in the St. Fintan's and Robinsons deposits but are found near the top of the Fischells Brook deposit, where sylvite layers 2 to 5 cm thick alternate with the halite. In most occurrences in the other two holes, the potassic salts are intergrown with halite in the salt beds, and polyhalite occurs both in the salt beds and interbedded with mudstones in the Fischells Brook and Robinsons deposits. Anhydrite and gypsum form up to 25% of individual salt beds, where they may occur as disseminated crystals, clots, angular chunks and blebs (Hooker Chemical Corporation, 1968, 1973). The clots, which may imply nodules, are up to 10 cm in diameter and enclose shaly impurities. Beds of anhydrite, 5 to 10 cm thick, also occur and these enclose cubic crystals of halite; anhydrite occasionally rims salt crystals in the salt beds. The deposits become richer in sulfates with depth and in the Fischells Brook drill hole, sulfate-rich salt sections with up to 40% anhydrite and/or gypsum alternate with sulfate-poor salt sections.

The clastic rocks associated with the salt occur as blebs, streaks, partings, beds or sequences up to 6 m thick. They are gray, green-gray or black calcareous shales and mudstones. Thicker beds frequently enclose nodular(?) anhydrite (the 'swells' of Hooker Chemical Corporation, 1973). Other sediments are red siltstones and brown, fine dolomite.

Interpretation of lithofacies S: The salt and sulfate deposits of the Jeffrey's Village Member are generally poorly known. Interpretation of their origin thus relies heavily upon the associated lithofacies and their general position in the succession.

The salt deposits formed in several large, isolated or interconnected, subsiding depressions (Figures 33 and 34). The salts are believed to have been precipitated at the same time halite-bearing, fine siliciclastics (lithofacies N to Q) of the lower Fischells Brook section were being laid down farther to the north. They were thus probably deposited in salinas that were surrounded by a complex of evaporitic mudflats and shallow hypersaline ponds (lithofacies N to Q). This implies that the depressions formed basins with restricted connection or periodic cut off from the main marine basin. The stratified, 'dirty' salt and mud deposits of the St. Fintan's and Robinson deposits support this concept; the salt beds were precipitated during repeated marine flooding and evaporation, but were subjected to intervals of high terrigenous input. Cleaner, thicker salt in the Fischells Brook deposit possibly formed in an isolated inner basin with only minor accumulation of terrigenous fines. Passage upward from sulfates to halite and then halite and potassic salts in this deposit suggests gradually increasing salinities with time.

In the upper half of the member, gypsum beds are associated with algal carbonates and redbeds. They appear to be limited in areal distribution. This suggests that they accumulated in hypersaline pools (Friedman et al., 1973) or in coastal sabkhas behind shoreline barriers such as described by Levy (1977a) on the Sinai Peninsula.

Paleocurrents of the Robinsons River Formation

Paleoflow trends northwestward and southwestward occur in nonmarine lithofacies of the Robinsons River Formation.

A dispersed, radiating, fan-shaped distribution with a northwestward vector occurs in alluvial fan deposits along the southeast margin of the subbasin in the Mollichignick and Overfall Brook Members (Figure 32C). At Flat Bay, a polymodal radial distribution (Figure 32A) is found which is related to the interference of overlapping alluvial fans that lay along the northern, northeastern and southeastern margins of the narrow, northeastern closure of the subbasin (see lithofacies E). No paleocurrents were measured in the pebbly arkoses of the Brow Pond lentil.

Basinward of the marginal alluvial fans, paleoflow associated with braided streams and sheetflood deposits in the Mollichignick Member has a pronounced mean southeast to northwest flow vector defined by parting lineations and trough axes. Ripple cross-lamination and crossbeds give a more radial distribution around the northwestward vector. The rose diagrams of these structures (Figure 32C) also suggest a secondary northeast-southwest paleocurrent trend, which is supported by the few parting lineations.

In the Jeffrey's Village Member, current directions are not so strongly oriented but data indicates both a northwestward vector and southwesterly to westerly paleoflow (Figure 32B). Paleoflow in channel sandstones is dominantly northwestward with a secondary flow to the southwest. The latter is important in sheet-like sandstones of lithofacies B interpreted as shallow, ephemeral braided stream deposits located on a distal alluvial plain. In these sandstones, the same vector is shown by both parting lineation and current-ripple directions.

Southwestward paleoflow along the subbasin axis predominates only in fluvial deposits of the Highlands Member (Figure 32B).

Paleocurrents in marine lithofacies of the Robinsons River Formation are fundamentally different from those of nonmarine rocks. The former fall into two categories; the first associated with deltaic sediments and mudrocks of the lower part of the Jeffrey's Village Member and the second associated with lithofacies L and M in the upper part of the Jeffrey's Village Member and in the Mollichignick Member.

In the lower Jeffrey's Village Member, sands deposited by fluvial-dominated distributary channels prograded south to southwestward. Some crossbeds in the sandstones however suggest that a northeast to eastward vector is present. This would give a bipolar distribution and suggests tidally influenced deltas (Wright, 1978). Paleocurrents in the halite-bearing siltstones and varicolored mudstones give a polymodal distribution. Ripple crests in associated rippled sandstones trend almost due east-west (Figure 32D) and this suggests east-west trending shorelines in interdelta areas in the north of the subbasin at the time of formation.

Straight, wave-formed ripple crests in marine sequences of the upper part of the Jeffrey's Village Member give east and northeast crest trends in the central part of the St. George's Bay lowlands and southeast to east crest trends in the north. Current-ripple bedding associated with parting lineations in shoreline sandstones all give a pronounced southeastward paleoflow, directly opposite to that found in associated fluvial strata and generally perpendicular to the ripple-crest trends (Figure 32D). This suggests shorelines were parallel to the general outline of the present subbasin and currents were generated by onshore eastward-directed waves or currents. Pronounced southeastward paleoflow of current indicators also occurs in the marine siliciclastics of the Mollichignick Member.

The interplay of marine, lacustrine and fluvial environments each affected the paleoflow distribution within the subbasin. When marine or lacustrine transgression flooded the subbasin, baselines moved close to the basin margins so that streams flowed but short distances perpendicular to and generally northwestward from the basin margins to the water body. Lakes and seas, however, retreated as alluvium prograded into the subbasin and the floodplain widened. At times marine conditions were displaced from at least the present onshore area of the subbasin, and southwestward fluvial paleoflow was established along the basin axis. Northwestward paleoflow perpendicular to the basin margins was maintained for distances of a few to perhaps 16 km beyond which current flow was redirected southwestward.

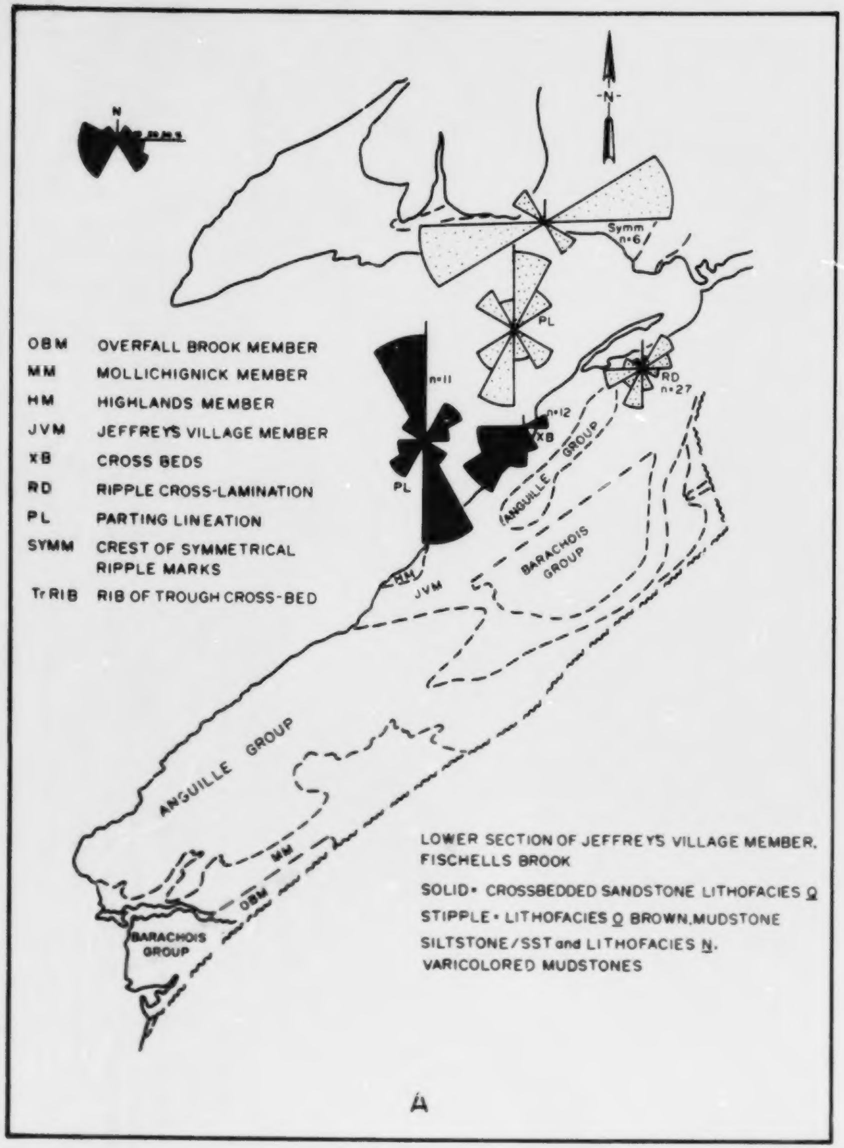
Marine flooding of the basin was probably from the west and northwest. Shorelines, suggested by ripple-crest trends and predominant eastward direction of current-ripple bedding, were parallel to the present basin boundaries.

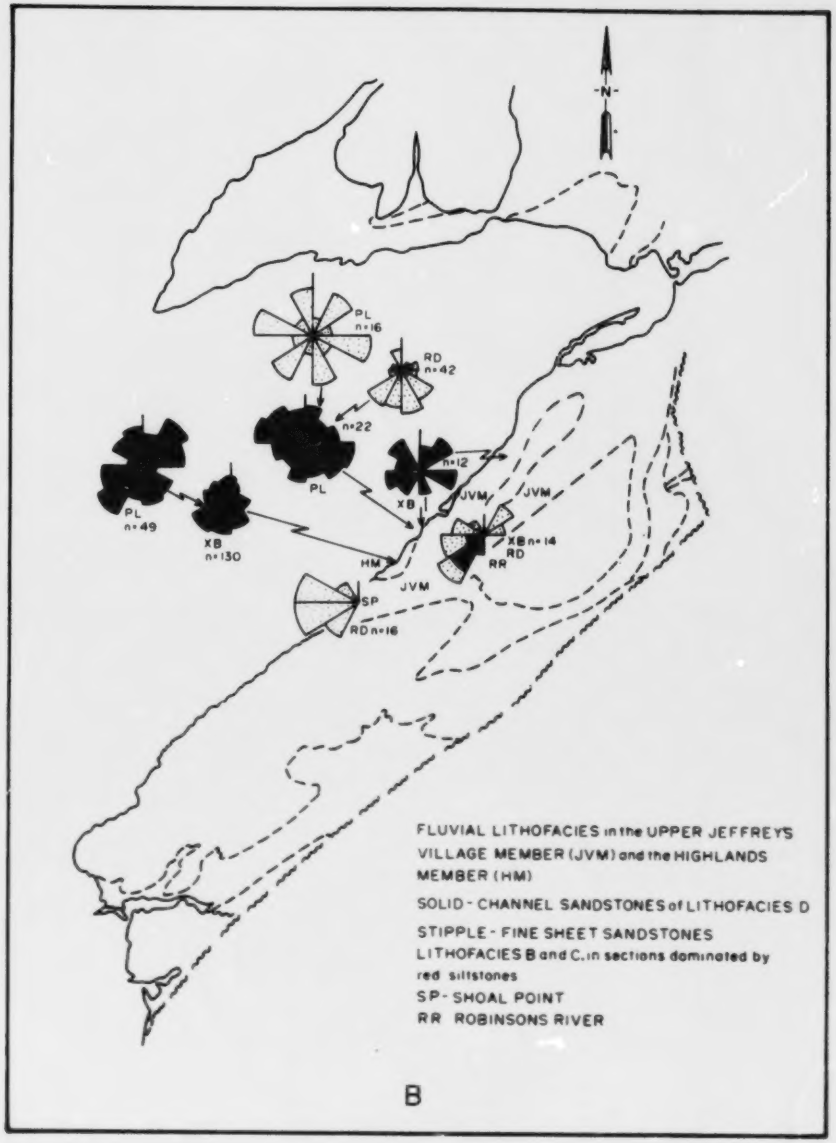
Paleontology, age and correlative deposits of the Robinsons River Formation

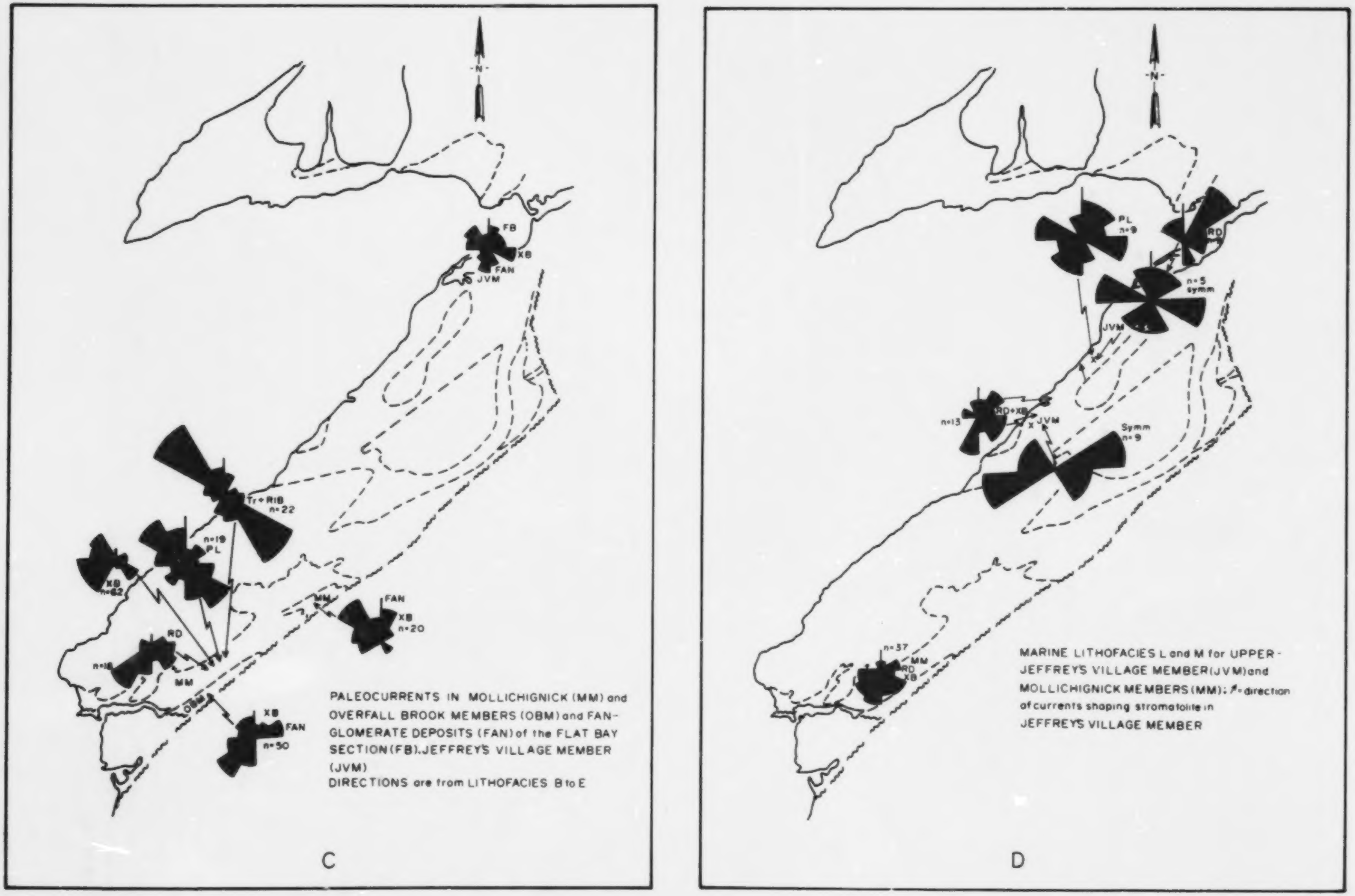
Macro- and micro-faunas and miospores have been recovered from rocks of the Jeffrey's Village and Mollichignick Members.

Shelly macrofossils, foraminifera and conodonts occur in the limestones of the Jeffrey's Village Member. The shelly fauna was collected mostly from the Fischells and Barachois limestones (Bell, 1948; Fong, personal communication, 1976) and the Crabbes limestone (McGlynn, personal communication, 1979) (see Table 6). Foraminifera collected from the Crabbes limestone were identified by Mamet (1968). Foraminifera were also noted in thin section study of carbonate subfacies of the Fischells limestone, limestone JVL-2 (see Figure 31) and limestones in the "round valley" area, Codroy lowlands. They included the forms *Biseriammina*, *Endothyra*, *Palaeotexturalia*, *Pseudoglomospira*, *Endothyranopsis*, *Tuberitina* and calcispheres (after Mamet, 1970). The bryozoa *Streblotrypa biformata* and the bivalve *Aviculopecten* were also collected from quartzose sandstones in the "round valley".

Three faunal assemblages were recently proposed for conodonts that occur in limestones of the Jeffrey's Village Member (von Bitter and Plint-Geberl, 1979, 1982). The lower


OBM OVERFALL BROOK MEMBER
MM MOLLICHIGNICK MEMBER
HM HIGHLANDS MEMBER
JVM JEFFREYS VILLAGE MEMBER
XB CROSS BEDS
RD RIPPLE CROSS-LAMINATION
PL PARTING LINEATION
SYMM CREST OF SYMMETRICAL RIPPLE MARKS
Tr RIB RIB OF TROUGH CROSS-BED
N
Symm n=6
PL
n=11
PL
n=12 XB
RD n=27
ANGUILLE GROUP
BARACHOIS GROUP
HM
JVM
MM
OBM
BARACHOIS GROUP
LOWER SECTION OF JEFFREYS VILLAGE MEMBER, FISCHELLS BROOK
SOLID = CROSSBEDDED SANDSTONE LITHOFACIES Q
STIPPLE = LITHOFACIES Q BROWN, MUDSTONE SILTSTONE/SST and LITHOFACIES N. VARICOLORED MUDSTONES
A


N
PL n=16
RD n=42
n=22
PL
n=12
XB
PL n=49
XB n=130
JVM
JVM
HM
JVM
XB n=14
RD
RR
SP
RD n=16
FLUVIAL LITHOFACIES in the UPPER JEFFREYS VILLAGE MEMBER (JVM) and the HIGHLANDS MEMBER (HM)
SOLID - CHANNEL SANDSTONES of LITHOFACIES D
STIPPLE - FINE SHEET SANDSTONES LITHOFACIES B and C, in sections dominated by red siltstones
SP - SHOAL POINT
RR ROBINSONS RIVER
B



-N-
FB
XB
FAN
JVM
Tr+RIB
n=22
n=19
PL
XB
n=62
MM
FAN
XB
n=20
RD
n=18
MM
OBM
XB
FAN
n=50
PALEOCURRENTS IN MOLLICHIGNICK (MM) and OVERFALL BROOK MEMBERS (OBM) and FAN-GLOMERATE DEPOSITS (FAN) of the FLAT BAY SECTION (FB). JEFFREYS VILLAGE MEMBER (JVM)
DIRECTIONS are from LITHOFACIES B to E
C
-N-
PL
n=9
RD
n=5
symm
JVM
n=13
RD+XB
X JVM
Symm
n=9
n=37
MM
RD
XB
MARINE LITHOFACIES L and M for UPPER-JEFFREYS VILLAGE MEMBER (JVM) and MOLLICHIGNICK MEMBERS (MM); ↗= direction of currents shaping stromatolite in JEFFREYS VILLAGE MEMBER
D

Figure 32: Paleocurrent data for different members and nonmarine and marine lithofacies of the Robinsons River Formation.

fauna, which occurs in the Barachois and Fischells limestones, is characterized by *Taphrognathus* n. sp. *A*. (von Bitter and Plint-Geberl, 1979, 1982) and also includes *Cavusgnathus regularis* type, *Bispathodus* sp., *Spathognathodus* n. sp. *A*. and *Spathognathodus campbelli*.

The middle fauna is limited to the Heatherton limestone and contains a small form of *Cavugnathus windsorensis* but excludes *Taphrognathus*. Von Bitter and Plint-Geberl (1982) used the fauna to correlate the Heatherton limestone with the Black Point limestone of the Codroy area, whereas here, the latter is placed at the top of the Codroy Road Formation, perhaps 1000 m lower in the Codroy Group succession than the Heatherton limestone. Von Bitter and Plint-Geberl's correlation is not accepted on lithological grounds as 'Codroy Breccias' are present above both the Black Point limestone near Codroy, and the Cormorant limestone at Ship Cove, the latter being generally accepted as older than the Heatherton limestone (Bell, 1948; von Bitter and Plint-Geberl, 1982). An environmental control, principally hypersalinity, is rather believed to control the similar faunas of the Heatherton and Black Point limestones. This environmental conclusion is strengthened by the occurrence with both "limestones" of gypsum, codiacean algae, serpulid worms and extensive diagenesis of original carbonate mud. Hypersalinity was also used to explain the small form size of *C. windsorensis* in basal Windsor and Codroy limestones (von Bitter and Plint-Geberl, 1982).

The upper fauna occurs in the Crabbes limestone and in a shale-carbonate-sandstone sequence (*Nodosinella* band, Bell, 1948) that occurs 100 m below the Crabbes limestone. It contains *Gnathodus scotiaensis* plus *Cavusgnathus regularis* type, *Hindeodus cristulus* and some specimens of *C. windsorensis* and "*Bispathodus* sp.".

Macrofauna and microflora, which are scarce and poorly preserved in the Mollichignick Member, are listed in Table 9. Macrofossils were listed by Utting (1966) from two fossil-bearing zones. The lower zone is located on the North Branch River and is said to contain the bivalves *Murchisonia(?)* and *Streblopteria* sp. and the ostracod *Glyptopleura sagae*. The upper fauna was collected from a number of beds near Limestone Brook and Gillans Island on the Grand Codroy River. It was reported to include the gastropods *Bucanopsis* sp., *Bulimorpha maxneri*, *Murchisonia gypsea*, *Murchisonia (Stegocoelia) compactoidea*, *Naticopsis howi* and *Platyschisma(?) dubium*, the bivalves *Edmondia hartti*, *Schizodus fundiensis(?)*, *Leptodesma(?)* sp., *Sanguinolites parvus(?)* and *Sanguinolites straitogranulatis*, the ostracod *Paraparchites* sp. and the straight cephalopod *Michelinoceras(?) vindobonense(?)*. Recently, a shelly fauna identified by G. McGlynn (personal communication, 1979) was collected on Mollichignick Brook from strata laterally equivalent to Utting's upper zone and also from Utting's locality 2 at Gillans Island. The fauna contained *Edmondia hartti*, *Modiolus hartti*, *Schizodus cuneus*, *S. densyi* and also unidentifiable brachiopods.

A miospore assemblage identified by Utting (personal communication, 1978) was recovered from Mollichignick rocks immediately beneath the upper faunal beds of Utting (1966). The assemblage included *Punctatisporites planus*, *Auroraspora macra*, *Rugospora minuta*, *Verrucosisporites morulatus*, *Punctatisporites irrasus*, *Endosporites micromanifestus*, *Endosporites minutus*, *Anaplanisporites* sp., *Lycospora noctuina* var. *noctuina*, *Cyclogranisporites* sp., *Crassispora trychera*, *Secarisporites remotus*, *Knoxisporites stephanephorus*, *Granulatisporites tuberculatus*, *Cyclogranisporites palaeophytus*, *Dic-*

MOLLICHIGNICK MEMBERS, ROBINSONS RIVER FORMATION

MACROFOSSILS

PELECYPODS

- *Edmondia hartti*
- Leptodesma sp.
- *Modiolus hartti*
- Sanguinolites parvus
- Sanguinolites striatogranulatus
- *Schizodus cuneus*
- *Schizodus denyi*
- Streblopteria sp.

GASTROPODS

- Bucanopsis
- Bulimorpha maxneri
- Murchisonia gypsea
- Naticopsis howi
- Platyschisma dubium
- Stegocoelia compactoides

CEPHALOPODS

- Michelinoceras vindobonense ?

OSTRACODS

- Glyptopleura sagae ?
- Paraparchites sp.

Also noted crinoid ossicles and unidentifiable *brachiopods*

Fauna from localities on Grand Codroy River listed by Utting (1966) and samples (italics) from Mollichignick Brook identified by G. McGlynn (personal communication, 1979).

MIOSPORES

- Punctatisporites planus
- Auroraspora macra
- Rugospora minuta
- Verrucosisporites morulatus
- Punctatisporites irrasus
- Endosporites micromanifestus
- Endosporites minutus
- Anaplanisporites sp
- Lycospora noctuina var noctuina
- Cyclogranisporites sp
- Crassispora trychera
- Secarisporites remotus
- Knoxisporites stephanephorus
- Granulatisporites tuberculatus
- Cyclogranisporites palaeophytus
- Dictyotriletes cf. D. sagenoformis
- Schopfipollenites sp
- Retusotriletes incohatus
- Spelaeotriletes sp

Flora recovered from sample collected on Grand Codroy River, 1 km northeast of Limestone Brook, identified by Utting (personal communication, 1978).

WOODY CAPE FORMATION

CAPELIN COVE	WOODY COVE
BRACHIOPODS	
Ambocoelia acadica	Ambocoelia acadica
Beecheria sp.	Beecheria sp
Buxtonia cogmagunensis	*Buxtonia cogmagunensis*
Martinia galataea	*Diaphragmus avonensis Bell*
Ovatia lyelli	Martinia galataea
Pugnoides sp. (Bell)	Ovatia lyelli
Romingerina anna	Romingerina anna
Schellwienella kennetcookensis	Spirifer n. s
Spirifer nox	
PELECYPODS	
Aviculopecten lyelli	Edmondia hartti
Cypricardella acadica	Leptodesma dawsoni
Edmondia hartti	Leptodesma sp. (Bell)
Modiolus hartti	Modiolus hartti
Sanguinolites striatogranulatus	Sanguinolites straitogranulatus
Schizodus cuneus	Sanguinolites niobe
Schizodus fundensis	Schizodus cuneus
Spathella insecta	*Schizodus fundensis*
Streblopteria debertianum	Schizodus richardsoni
Streblopteria simplex	Spathella insecta
GASTROPODS	
Anematina cf. proutana	Aclisina acutula
Bellerophon sp	*Bellerophon sp*
Euphemites cf. urei	Euphemites cf. urei
Platyschisma dubium	*Naticopsis sp*
Pseudozygopleura sp	Platyschisma dubium
Stegocoelia abrupta	*Pseudophorus minutus*
Stegocoelia compactoides	Pseudozygopleura sp
	Stegocoelia abrupta
	Stegocoelia compactoides
	Straparollus sp
CEPHALOPODS	
	Michelinoceras sp. indet.
	Poteriocerας sp. Bell
TRILOBITA	
Paladin eichwaldi	*Paladin eichwaldi*

Plus unidentified ostracods

Fauna listed from three fossil bearing horizons in Woody Cove and two in Capelin Cove collected and identified by G. McGlynn (personal communication, 1979), with additional forms (italics) added from Hayes and Johnson (1938) and Utting (1966).

MIOSPORES

- Apiculatisporis sp.
- Auroraspora macra.
- Calamospora sp.
- Crassispora trychera,
- Cyclogranisporites palaeophytus.
- Dictyotriletes sp.
- Endosporites micromanifestus.
- Granulatisporites tuberculatus.
- Knoxisporites stephanephorus.
- Lycospora noctuina var noctuina.
- Punctatisporites planus,
- Retusotriletes incohatus.
- Rugospora minuta.
- Schopfites claviger.
- Spelaeotriletes sp.
- Verrucosisporites morulatus

Assemblage collected from four samples in Capelin Cove, identified by J. Utting (personal communication, 1978). spore preservation generally poor

CONODONTS

- Apatognathus spp
- Cavusgnathus windsorensis
- Cavusgnathus regularis
- Gnathodus sp.
- Gnathodus bilineatus
- Gnathodus girtyi
- Mestognathus spp
- Ozarkodina laevipostica
- Spathognathus n. sp. A
- Spathognathus campbelli
- Spathognathodus scitulus

Plus several unidentified elements, genus and species.

Assembled from several stations in section in Capelin Cove collected and identified by von Bitter and Plint Geberl (1982)

Table 9: Fauna and microflora compiled for the Mollichignick Member (Robinsons River Formation) and the Woody Cape Formation.

tyotriletes cf. *D. sagenoformis*, *Schopfipollenites* sp., *Retusotriletes incohatus* and *Spelaeotriletes* sp..

No conodonts were retrieved from fossil beds in the Mollichignick Member (von Bitter, personal communication, 1980).

The Jeffrey's Village Member was deposited during a time interval equivalent to subzone B - lower subzone C of the Windsor Group of Nova Scotia. The shelly fauna and lower *Taphrognathus* conodont fauna recovered from the lower limestones of the Jeffrey's Village Member are both characteristic of Windsor subzone B faunas (Bell, 1948; McGlynn, personal communication, 1979; von Bitter and Plint-Geberl, 1978, 1982). This suggests the succession associated with the Fischells limestone may be correlated in general terms with Windsor Group strata containing the Miller and Maxner limestones in Nova Scotia (von Bitter and Plint-Geberl, 1982).

Foraminifera and the conodont fauna recovered from the Crabbes limestone suggests it belongs to lower subzone C (Mamet, 1968; von Bitter and Plint-Geberl, 1982) of the Windsor Group which contain the Herbert River limestone of Nova Scotia (Moore and Ryan, 1976). The possible presence of *Sanguinolites niobe* in the Crabbes limestone also supports this age and correlation (McGlynn, personnal communication, 1979; Moore, personal communication, 1978). Conodonts suggest lower subzone C ranges down to the *'Nodosinella'* band of Bell (1948) some 100 m below the Crabbes limestone.

In the Mollichignick Member, the original identifications of the poorly preserved shelly fauna suggested to Utting (1966) a Windsor subzone B age for the member. However, the recent identification of bivalves such as *Edmondia hartti* and *Modiolus hartti* support a Windsor subzone D age (McGlynn, personnal communication, 1979) for the member which is broadly supported by miospores and ostracods. Utting (written communication discussing the spores, 1978) reported, "The presence of a typical Windsor assemblage along with *Secarisporites remotus*, *Schopfipollenites* sp., and undescribed species of *Anaplanisporites* and *Spelaeotriletes* suggests that the assemblage may be attributed to Assemblage II found in the Upper Windsor of Nova Scotia (macro-faunal subzones C, D, and E)".

The ostracods recorded by Utting (1966) were assigned a late Chesterian age by comparison to type faunas in the U.S.A. (W. D. Smith, University of Illinois, personal communication, in Utting, 1966).

The Windsor subzone D age suggests the Mollichignick Member correlates with the Woody Cape Formation on the coast at Capelin Cove. Both units are thus correlated with an unnamed formation containing the Avon and Meander River limestones in Nova Scotia (Moore and Ryan, 1976).

The Highlands Member overlying the Crabbes limestone is probably of subzone C age. The Overfall Brook Member which occurs 700 m above the last marine fossil-bearing zone in the Mollichignick Member is here placed in the Codroy Group. This is based primarily upon similarity of arkosic lithofacies interbedded in the Mollichignick Member to those in the Overfall Brook Member, suggesting a continuing phase of deposition. It is acknowledged, however, that the Overfall Brook Member may represent the first phases of Cansoan sedimentation, typified in southwest Newfoundland by the Searston Formation as previously suggested by Baird and Cote, (1964), Utting (1966) and Belt (1969).

Depositional environment of the Robinsons River Formation

Discussion of the Robinsons River Formation is complicated by the division of the succession into two geographic areas, the St. George's Bay lowlands and Codroy lowlands. The exact spatial and time relationship of the Jeffrey's Village and Highlands Members in the north to the Mollichignick and Overfall Brook Members in the south is not clear, although the base of the Mollichignick Member may overlap upper strata of the Highlands Member. For these reasons, the Jeffrey's Village and Highlands Members are discussed separately from the Mollichignick and Overfall Brook Members.

Jeffrey's Village and Highlands Members

The succession in the two members forms a continuum and proceeds through four separate depositional stages. Sedimentation began in the Jeffrey's Village Member with progradation of fine red alluvial sediment from the southeast, and retreat of marine conditions into the northeast of the subbasin. This stage was followed by widespread expansion of shallow evaporitic conditions in the north of the subbasin when fine, drab colored siliciclastics and several major salt sequences accumulated. The third stage in the depositional history of the area started roughly with the deposition of the Fischells limestone. It consisted of thick nonmarine redbeds in which thin marine sequences were intercalated. The redbeds gradually gained ascendency upwards. The fourth stage occurred above the Crabbes limestone and was confined to the Highlands Member. At this time the axial area of the subbasin was blanketed with abundant red sandy alluvium and floodplain siltstones and coarser pebbly red alluvium was deposited to the northeast and towards the basin margins.

Some general remarks are appropriate:

a) The deposition of the succession occurred in an inherited semiarid to arid, hot climate similar to that of the underlying Codroy Road Formation. Evaporites primarily reflect this aridity in the lower Jeffrey's Village Member. Nodular caliche in fluvial rocks (Gile et al., 1966; Reeves, 1970), calcrete, and carbonates (James, 1972) in the upper Jeffrey's Village Member, together with caliches in the Highlands Member, support the presence of continued semiarid climatic conditions after completion of salt deposition.

b) The paleocurrents and lithoclasts in the members indicate that sediment was derived from mountains north-northeast, northeast and southeast of the subbasin (Table 9 and Figure 32). Three different geological terranes were eroded to supply pebble beds into the Flat Bay area. They were: (1) the Cambro-Ordovician platformal rocks and ophiolitic strata of the Humber Arm allochthon highlands to the north, (2) the Fleur de Lys metasediments to the northeast and (3) the volcanic and granitic rocks of the Topsails Igneous Complex and metamorphic rocks to the southeast. The westerly directed paleocurrent data for the remaining redbeds of the Jeffrey's Village Member and the importance of silicic volcanic pebbles in channel sandstones in the axial area of the subbasin suggest that the principal provenance in the upper half of the Jeffrey's Village Member and in the Highlands Member lay to the southeast.

Expected survival distances for pebbles composed of schist, phyllite and limestone transported as river gravel is generally less than 23 km (Cameron and Blatt, 1971). This fact may indicate that the rivers were mostly short, steep-gradient types in the north and northeast, and probably also southeast of the Long Range Fault.

c) Paleocurrent distributions for the Jeffrey's Village and Highlands Members suggest that there were two main paleoflow directions. The first, which is prominently displayed in redbeds of the Jeffrey's Village Member, is to the west or northwest. The second vector is to the southwest along the basin axis. Such paleoflow vectors occur in the deltaic sandstones of the lower evaporitic succession of the Jeffrey's Village Member and in the high sinuosity fluvial deposits of the Highlands Member.

d) As in the Ship Cove and Codroy Road Formations, marine environments are concentrated toward the northwest. This is supported by the distribution of lithofacies on a broad scale and from features within individual subfacies as follows: (1) at the base of the Jeffrey's Village Member, fine redbeds appear to cover the subbasin from Codroy to just north of Ship Cove; on the other hand, green, gray and black fine grained beds of probable marine origin with only minor brown beds are found in the Fischells Brook area in the north; (2) ripple marks suggest that shorelines were parallel to the present boundaries of the subbasin and paleocurrent directions in marine lithofacies are mostly opposite to those of the alluvial sediments, suggesting marine conditions to the west and northwest and shorelines to the northeast and southeast (see Figure 34B and C); (3) distribution higher in the Jeffrey's Village Member of marine lithofacies and of carbonate subfacies and the orientation of stromatolites suggest that open marine conditions lay to the northwest and shallow quiet shorelines were close to the present basin margins.

During peak flooding of the subbasin, marine conditions extended at least from the northern part of the Codroy lowlands to the region of St. George's, a distance of 75 km. The marine basin probably extended westward beneath St. George's Bay. Marine carbonates form only 8 to 10% of the succession. However, the total succession probably directly influenced by a marine environment is closer to 50%. Of this, 40% occurred in the lower evaporitic section of the member.

With these generalities in hand the four stages of sedimentation for the two members are now assessed.

Stage I - Northwestward to westward prograding alluvium composed of lithofacies A and B dominated the basal section of the Jeffrey's Village Member in the south and centre of the subbasin. Drab colored, fine beds near Fischells Brook suggest that quiet, shallow marine conditions remained in the north of the subbasin during this stage. Several thin carbonates were intercalated at the base of the fine redbeds in the south of the area. These marine sediments represent the last phases in this area of the marine events that had begun during the deposition of the Codroy Road Formation. The carbonates were subsequently karsted during regressions, forming the Codroy Breccias.

Stage II (Figures 33 and 34A) - Stage II encompasses the salt-bearing strata of the St. George's Bay lowlands which occupy the lower 550 to 1,600 m of

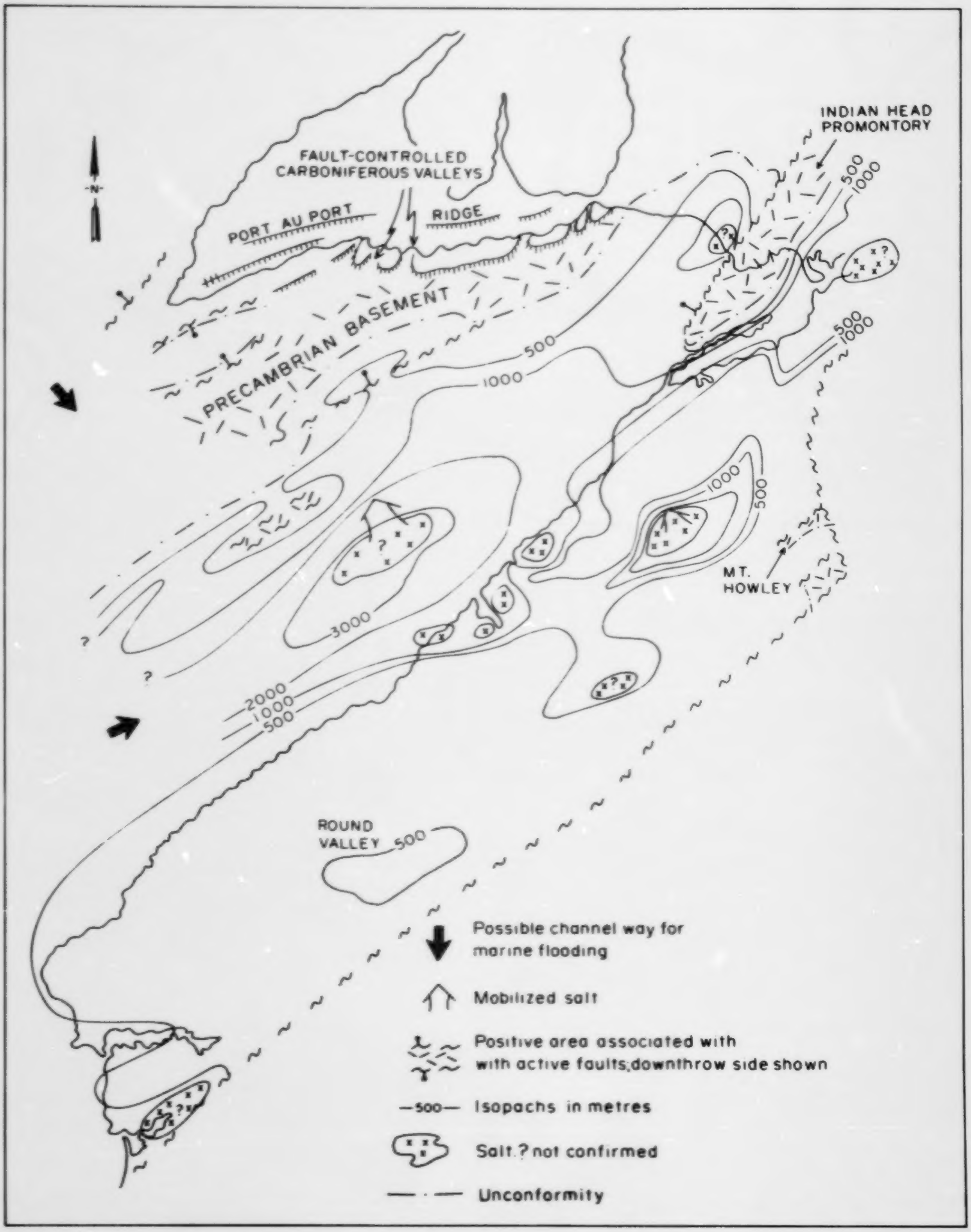

INDIAN HEAD PROMONTORY
N
FAULT-CONTROLLED CARBONIFEROUS VALLEYS
PORT AU PORT
RIDGE
PRECAMBRIAN BASEMENT
500
1000
3000
2000
1000
500
MT. HOWLEY
?
ROUND VALLEY
Possible channel way for marine flooding
Mobilized salt
Positive area associated with with active faults;downthrow side shown
—500— Isopachs in metres
Salt ? not confirmed
Unconformity

Figure 33: Partly speculative isopach map of the Bay St. George subbasin during deposition of the lower part of the Robinsons River Formation. Data compiled from drill holes, gravity and aeromagnetic maps, structural cross sections, logged sections and offshore seismic surveys. Structural highs, probable active faults and location of possible salt-filled depressions shown.

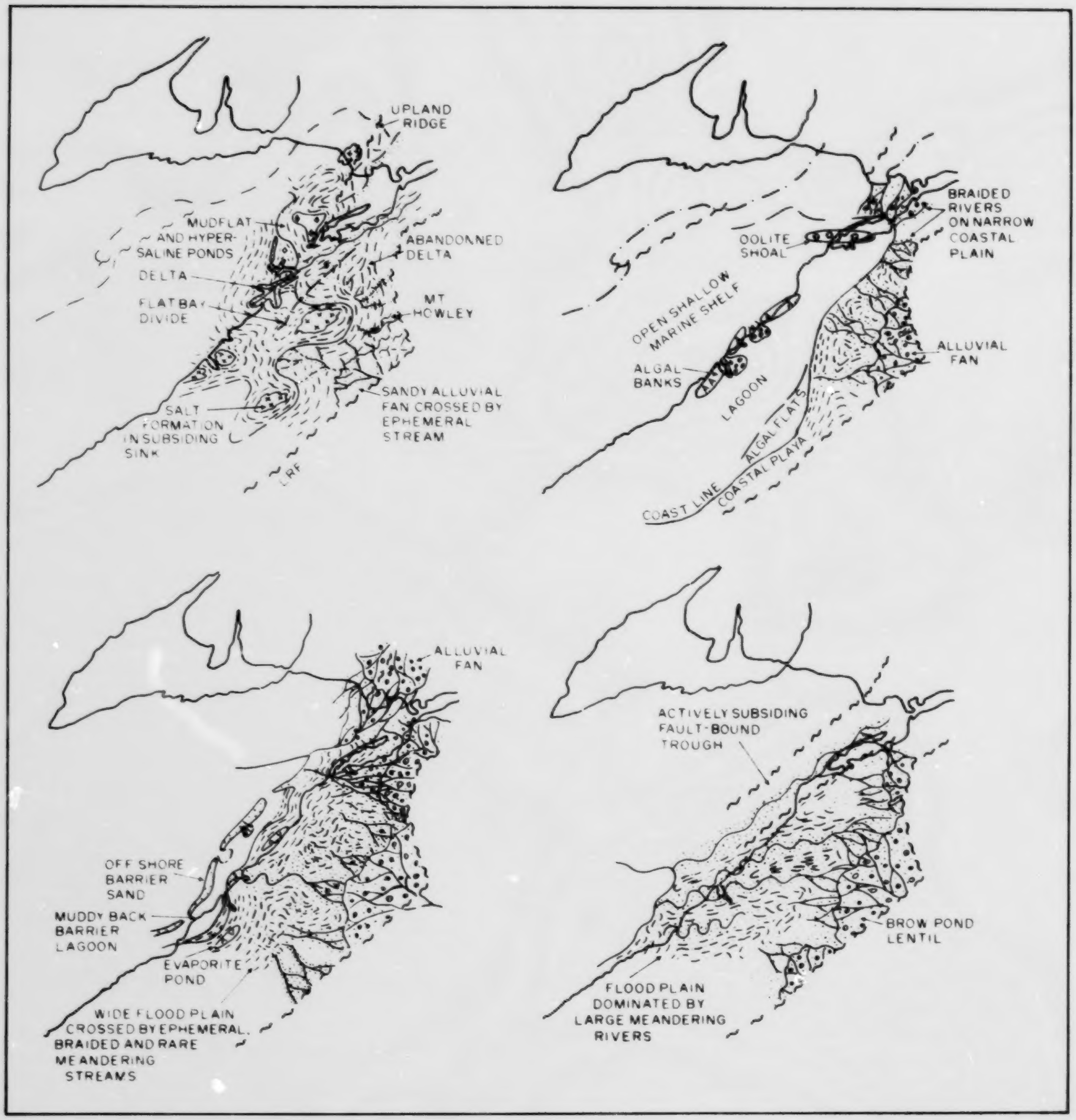

UPLAND RIDGE
MUDFLAT AND HYPER-SALINE PONDS
ABANDONNED DELTA
DELTA
FLAT BAY DIVIDE
MT HOWLEY
SANDY ALLUVIAL FAN CROSSED BY EPHEMERAL STREAM
SALT FORMATION IN SUBSIDING SINK
LRF
BRAIDED RIVERS ON NARROW COASTAL PLAIN
OOLITE SHOAL
OPEN SHALLOW MARINE SHELF
ALLUVIAL FAN
ALGAL BANKS
LAGOON
ALGAL FLATS
COASTAL PLAYA
COAST LINE
ALLUVIAL FAN
OFF SHORE BARRIER SAND
MUDDY BACK BARRIER LAGOON
EVAPORITE POND
WIDE FLOOD PLAIN CROSSED BY EPHEMERAL, BRAIDED AND RARE MEANDERING STREAMS
ACTIVELY SUBSIDING FAULT-BOUND TROUGH
BROW POND LENTIL
FLOOD PLAIN DOMINATED BY LARGE MEANDERING RIVERS

Figure 34: Possible reconstruction of the paleogeography of the northern part of the Bay St. George subbasin during the deposition of the Jeffrey's Village and Highlands Members of the Robinsons River Formation. (A) lower Jeffrey's Village Member; (B) lower part of upper Jeffrey's Village Member during widespread marine flooding; (C) dominantly nonmarine sedimentation in upper part of the Jeffrey's Village Member; (D) Highlands Member.

the Jeffrey's Village Member. Thickness data available (Figure 33) indicate that the salt probably formed in several rapidly subsiding depressions hosting considerably thicker sedimentary sections. Positive areas separated the depressions and received much thinner sedimentary cover. A topographic high over the site of the present Flat Bay anticline (Flat Bay divide) separated the thinner siliciclastic section at Fischells Brook, west of the anticline, from a thicker salt-bearing depression to the east (Fischells Brook salt deposit). It is also possible that the Anguille anticline formed a similar positive area.

The depressions were possibly isolated from open marine conditions but were periodically flooded as the basin subsided. Alternatively, a restricted connection might have been retained to the Windsor sea (Bell, 1929, 1948) which probably lay to the west. Shallow salinas were thus maintained in separate, partly interconnected depressions during a common geologic interval or formed at different times as separate areas of the subbasin began to subside actively.

Fine siliciclastics were deposited along the margins of the inland depressions as suggested by the 7 km distance separating the Fischells Brook section from the Robinsons salt deposit. Sedimentation at the basin margins alternated between delta outbuilding and widespread mudflat development. Small, bird's-foot type deltas prograded out into the shallow, sheltered, probably essentially tideless, inland sea. The lack of salt pseudomorphs in rock sequences related to delta building implies that a large inflow of freshwater may have occurred. The dimensions of the inland sea probably expanded, and the waters were diluted. This may account for the two salt sequences in the Robinsons salt hole separated by fine siliciclastics, the latter deposited during outbuilding of the lower delta sequence (Figure 20).

Mudflats covered by shallow, hypersaline ponds were established away from active delta areas or when delta growth ceased. Rapid changes of lithofacies such as occur in the Fischells Brook section could be the response to changing climatic conditions. Alternatively, the facies variation possibly involved major shifts of river channel direction (Leeder, 1978) either on alluvial fans or high on the delta plain. Not only would this cause facies changes, but the standing body of water would become increasingly hypersaline as inflow of freshwater was cut off. A positive divide might easily have acted as a control for such channel switching. During exceptional floods, rivers discharging from a mountain source to the northeast might escape from existing channels feeding one depression and begin to flow to another area of the same depression or into a separate depression altogether. A recent example of such channel redirection occurred during catastrophic flooding in 1905 near the Gulf of California when the normally southward flowing Colorado River switched its flow northward to the Salton sink (Meckel, 1975; Stephen and Gorsline, 1975) and transformed a playa into a large lake, the Salton Sea. A similar process is envisioned to explain the changeable, vertical succession and the thick, salt-rich sections lying close to, but separate from, thinner, salt-poor sections. The importance of salt in the succession likely reflects arid conditions with very low rainfall and high evaporation (Kinsman, 1969, 1976). The conspicuous presence of delta sands must, therefore, point to a large perennial river carrying only fine sand and mud detritus. It probably originated in a distant mountain source where precipitation was higher and more persistent (Hardie et al., 1978). Petrology of the sands suggests that these mountains contained rocks similar to the Topsails igneous complex.

The salt was deposited toward the centres of the subsiding depressions. The general characteristics of the overall succession in the St. Fintan's and Robinsons salt deposits suggest that the salt formed under generally shallow conditions influenced by terrigenous input. Both sulfates and halite accumulated in the St. Fintan's deposit but gypsum is virtually absent in the Robinsons succession where salt is interbedded with shale. These facts suggest that the salinas were perhaps interconnected so that brine salinity increased and changed in composition from the outermost to the innermost depressions. Deposition of evaporite phases may have been similar to that described in the coastal sabkhas of the Sinai (Levy, 1977a and b) and the lagoons and tidal flats of Baja California (Holser, 1966; Phleger, 1969). In the outer water bodies, precipitation of sulfate and halite caused an increase in the brine chlorinity as the less soluble salts were removed. Spillover of this enriched brine into the inner salina occurred during renewed marine flooding. Consequently, halite was precipitated when evaporation resumed and the sulfate stage of precipitation was bypassed.

Shearman (1970) has emphasized the importance of salt redistribution and diagenesis by the action of evaporative pumping of groundwater brines during prolonged periods of evaporation and dessication. Polyhalite, found in the Codroy Group salt deposits, is known to form diagenetically in the salt flat deposits of Baja California (Holser, 1966) and suggests that similar diagenetic redistribution of salts occurred in the salt deposits of the Jeffrey's Village Member. The salt deposits probably formed in shallow water salinas with prolonged dessication leading to formation of extensive salt flats surrounded by the saline mudflats.

Stage III (Figure 34 B & C) - Stage III is represented by the stratigraphic interval between the Fischells limestone and the Crabbes limestone. It includes a mixed section of nonmarine redbeds as well as marine carbonates, evaporites and siliciclastics. The stage appears to have two parts, a lower 370 m thick section of regularly intercalated nonmarine and marine rocks and an upper 480 m thick section dominated by redbeds (Figure 20).

In the lower 370 m section as seen on Fischells Brook, redbeds dominated by lithofacies A and D are intercalated with eight dominantly calcareous, marine units. The characteristics of the nonmarine strata suggest that they were deposited on a narrow coastal plain that was crossed by braided river channels. The Flat Bay section, however, indicates that a carbonate-rich coastal playa flat composed of shaly siltstones and flanked by alluvial fans occurred in the northeast of the subbasin. The alluvial fans overlapped each other as they built from the north, northeast and southeast into the narrowing northeast corner of the subbasin. Other alluvial fans lay along the southeast boundary of the subbasin. A major fan complex, the Brow Pond lentil, formed between the Steel Mountain anorthosite and the Long Range fault. Here, active sedimentation probably occurred after a prolonged interval of nondeposition which coincided with tilting and erosion of older deposits of the lentil. The alluvial fan probably then continued to grow during stage IV and perhaps also during deposition of the Mollichignick and Overfall Brook Members.

Old age caliches in red siltstones and thin dolomitic caliches that bounded some of the channel sandstones suggest that active sedimentation was intermittent and little deposition occurred locally upon the floodplain for thousands of years (Allen, 1974; Leeder, 1975).

Although outcrop is generally poor between the marine beds in the lower 370 m section of the Fischells Brook section, it appears that the deposition of the marine strata involved both relatively short transgressive-regressive events (e.g. Fischells limestone and JVL-2) and prolonged marine events. In the latter, marine flooding was maintained after the initial transgression (e.g. JVL-4 and 5, Flat Bay limestone and Crabbes limestone). Transgression over oxidized alluvium was rapid. Regression was effected slowly as marine sediments accreted within the shallow seas and alluvium prograded seaward along the shorelines. Marine flooding occurred from the west and northwest and maximum marine flooding probably occurred in the interval that deposited the Fischells limestone and JVL-2. At this time the inland seas extended at least as far south as the "round valley", Codroy lowlands.

The lowest marine beds (Figure 34B) include the Fischells, Barachois, and JVL-2 limestones of the St. George's Bay lowlands and the fossiliferous limestone of "round valley", Codroy lowlands. They consist of low- to moderate-energy carbonate shelf muds and muddy sand shoals. These sediments were deposited in shallow seas that supported a thriving burrowing fauna as well as crinoids, brachiopods, bryozoa, foraminifera, gastropods and cephalopods. Upward decrease of fossil content and diversity, often restricted to bivalves, gastropods and ostracods, together with the occurrence of thin stromatolites at the top of these carbonates suggests that salinities gradually increased as the seas shallowed.

Oolite shoals and stromatolite buildups typify the middle carbonate units, including the Heatherton limestone. They generally overlie low energy, fauna-poor, subtidal mudstones which lie at the base of most units. Stromatolite banks indicative of relatively high energy environments formed along shorelines or formed barriers behind which shallow, back-barrier lagoons and sandy, tidal flats occurred. Low faunal diversity and abundance, mostly ostracods, bivalves, gastropods and burrowing organisms, plus thin gypsum interbeds and occurrence of radial ooids suggest salinities were higher behind the barriers.

Gypsum, associated with redbeds and lumpy algal dolomites, was probably precipitated in hypersaline pools, lagoons and coastal sabkhas (Friedman et al., 1973; Horodyski et al., 1977; Levy, 1977a and b) that lay behind sand and carbonate barriers. The saline pools and lagoons encouraged formation of the lumpy algal carbonates. Locally, sandy shoreline sequences were also developed. Algal flats developed where siliciclastic detritus was low and the shoreline sheltered and flat.

Shallow seas were microtidal (Davies, 1964) similar to modern inland seas such as Shark Bay, Australia (Hagan and Logan, 1974a) and the Abu Dhabi coast of the Persian Gulf (Schneider, 1975). Tidal currents as well as storm wave action were, however, sufficient to generate high energy conditions locally within tidal channels and across barriers. They explain the presence of algal banks and local, high energy shoreline deposits.

The development of calcretes in the upper beds of carbonate units, the widespread dissolution of skeletal remains and the precipitation of blocky spar cements in porosity suggests that freshwater vadose diagenesis was common during the late histories of each carbonate unit. Diagenesis occurred when algal banks and exposed skeletal muds and packstones fell under the domination of meteoric waters as the sea withdrew or evaporated.

In the 480 m of the upper part of stage III, the redbeds are generally much finer grained with thick sandstones only sporadically developed. The fine red alluvium was deposited on an alluvial plain as flood plain siltstones and thin sheet sandstones. The latter are typified by sharp but not always erosive bases, flat bedding and cross-lamination. They were probably the flood deposits of shallow, possibly ephemeral, streams (Friend, 1978; McKee et al., 1967; Williams, 1971; Picard and High, 1973) or were produced by sheet wash outward from the lower slopes of alluvial fans (Heward, 1978b; Hardie et al., 1978).

Channel sandstone deposits are not common in the upper part of the stage. They occur most commonly (Figure 20) near the top of the member and as it is traced northeastward. Both low and high sinuosity streams occurred; the low sinuosity stream deposits are dominated by flat bedding. Fining-upward sandstone deposits up to 4 m thick, however, include both crossbedded and planar stratified sandstones that were probably laid down in meandering channels. If this sandstone thickness represents bankfull channel depth (Leeder, 1973), a channel width of about 40 m and meander belt width of about 390 m (Collinson, 1978b) seems probable. General scarcity of channel sandstones, presence of multistory channel sandstone deposits and locally thick levee and crevasse-splay deposits suggest that meander belts were stabilized on the alluvial plain and that the alluvial plain aggraded by overbank flooding. Planar crossbedded sandstones with mudcracked siltstone interbeds suggest that ephemeral braided streams also crossed the alluvial plain. Virtual absence of caliche in the upper section of the stage suggests sedimentation rates were high (Leeder, 1975).

In the upper section of the stage (Figure 34C), only two marine events occurred. These included gray shales and sandstones deposited in quiet lagoons flanked by prograding intertidal flats (Nodosinella band, Bell, 1948) and the final marine event, the Crabbes limestone at the top of the Jeffrey's Village Member. Skeletal and oncolitic lime mudstones and packstones, rich in a foraminiferid fauna (Mamet, 1968) characteristic of open marine biofacies (Mamet, 1970) indicate a return to a less restricted marine environment during deposition of the Crabbes limestone. The characteristics of the marine deposits of the upper part of the stage suggest the seas continued to be shallow and microtidal. The carbonates were also affected by some freshwater vadose diagenesis.

Stage IV (Figure 34D) - Stage IV is confined to the Highlands Member. It consists of repetitive fining-upward sequences of red sandstones and siltstones, deposited by high sinuosity river channels that traversed a flood plain. Bankfull thickness represented by the thickest channel sandstones of 11 m, suggests large rivers approximately 115 m wide (Leeder, 1973) and meander belt widths up to 1,100 m (Collinson, 1978b).

Mature and old caliche profiles (Reeves, 1970) support a semiarid climate during this stage for the subbasin and suggest that sedimentation at times ceased for tens of thousands of years in some areas of the flood plain (Allen, 1974; Leeder, 1975). The size of the river channels rules out ephemeral sedimentation. Rather, channel switching by avulsion (Allen, 1965a; Leeder, 1978) probably controlled floodplain and pedogenic development. Thick caliches were developed in abandoned areas of the alluvial system such as interfluvial ridges or elevated alluvial terraces (Allen, 1974; Allen and Williams, 1979) so that meander belts were stabilized for long periods.

In general, the dominance of young pedogenic profiles in red siltstones and the presence of pebble and sand size red mudclasts and nodular caliche intraclasts in channel sandstones suggest that overbank alluvium was steadily reworked as channels migrated laterally. Hence only young pedogenic profiles were able to form. This may imply that the subbasin subsided steadily allowing the rivers to migrate freely across the flood plain.

The reworking of oxidized overbank sediments in large part accounts for the intense red color of the channel sandstones and indicates the early formation of red pigment in the deposits (McPherson, 1980). Sudden and intense flashfloods on the flood plain, however, produced channel-bound intraformational conglomerates. This occurred when exceptionally high discharge capable of moving large volumes of detritus washed out both floodplain muds and thick caliche horizons, as is the case in modern semiarid areas (Wolman and Miller, 1960; Baker, 1977). Some of the thicker deposits of this type that occur near the top of the exposed section are ungraded and were probably deposited by larger, longer-lived braided streams.

The presence of the Windsor sea within or near the subbasin during deposition of the Highlands Member is supported by the two fossiliferous marine units in the lower part of the member.

Mollichignick and Overfall Brook Members

Sedimentation throughout the deposition of the two younger members in the Codroy lowlands is linked to a basin margin setting (Figure 35). This is reflected by the provenance of pebbles, the paleocurrent distributions and the importance of pebbly, coarse, arkosic and argillaceous sandstones of lithofacies E in the succession. Pebbles consisting of plutonic and metamorphic rock fragments support derivation of detritus from a mountain source in the vicinity of the Long Range Mountains. Presence of caliche (Allen, 1974; Leeder, 1975) and spidery plant rootlets (Sargaent, 1975) suggest that the basin possessed a semiarid climate at this time.

Mega- and basin-fill sequences 400 to 1,000 m thick of pebbly arkosic sandstones and of pebbly, muddy sandstones formed on alluvial fans adjacent to the active basin margin. The margin lay either coincident with the Long Range fault or more likely to the southeast along shear zones which are known to occur within the Long Range Mountains parallel to the Long Range fault (Chorlton, personal communication, 1980). This is supported by a scarcity, adjacent to the Long Range fault, of exceptionally coarse gravels and debris flow deposits typical of proximal, fan-apex deposits. An elongate aeromagnetic high (Geological Survey of Canada, 1971) occurs between South Branch and Coal Brook suggesting that basement occurs beneath the Mollichignick sediments basinward of the Long Range fault. This implies that the original southeast margin was locally irregular and changed in position as the narrow, fault-bounded basement wedges were uplifted along the active tectonic margin. Alternatively, the magnetic anomaly may imply that some volcanic rocks were extruded close to the Long Range fault within the lower part of the Mollichignick Member.

The alluvial fans of the Mollichignick Member, composed of muddy, brown-red pebbly sandstones, are mostly the products of sheet-flood (Bull, 1972; Heward, 1978b) in a semiarid climate. The fan sequence in the Overfall Brook Member, however, is composed of well washed arkoses which were deposited by braided streams, suggesting increased precipitation in the source area. Abundance of caliche units within the Mollichignick fan deposits, but their absence in the Overfall Brook fans, supports moderation of climate from semiarid to more humid at this time.

The marginal alluvial fans built basinward over axial floodplain deposits; this is clearly seen in the type section of the Mollichignick Member. The alluvial fans influenced paleoflow for much of the succession as sediment was dispersed northwestward from the fan slopes out onto the flood plain by sheet wash and braided streams (cf. Blissenbach, 1954; Hooke, 1967). Periodically, coarse pebbly detritus (lithofacies E) prograded out over the

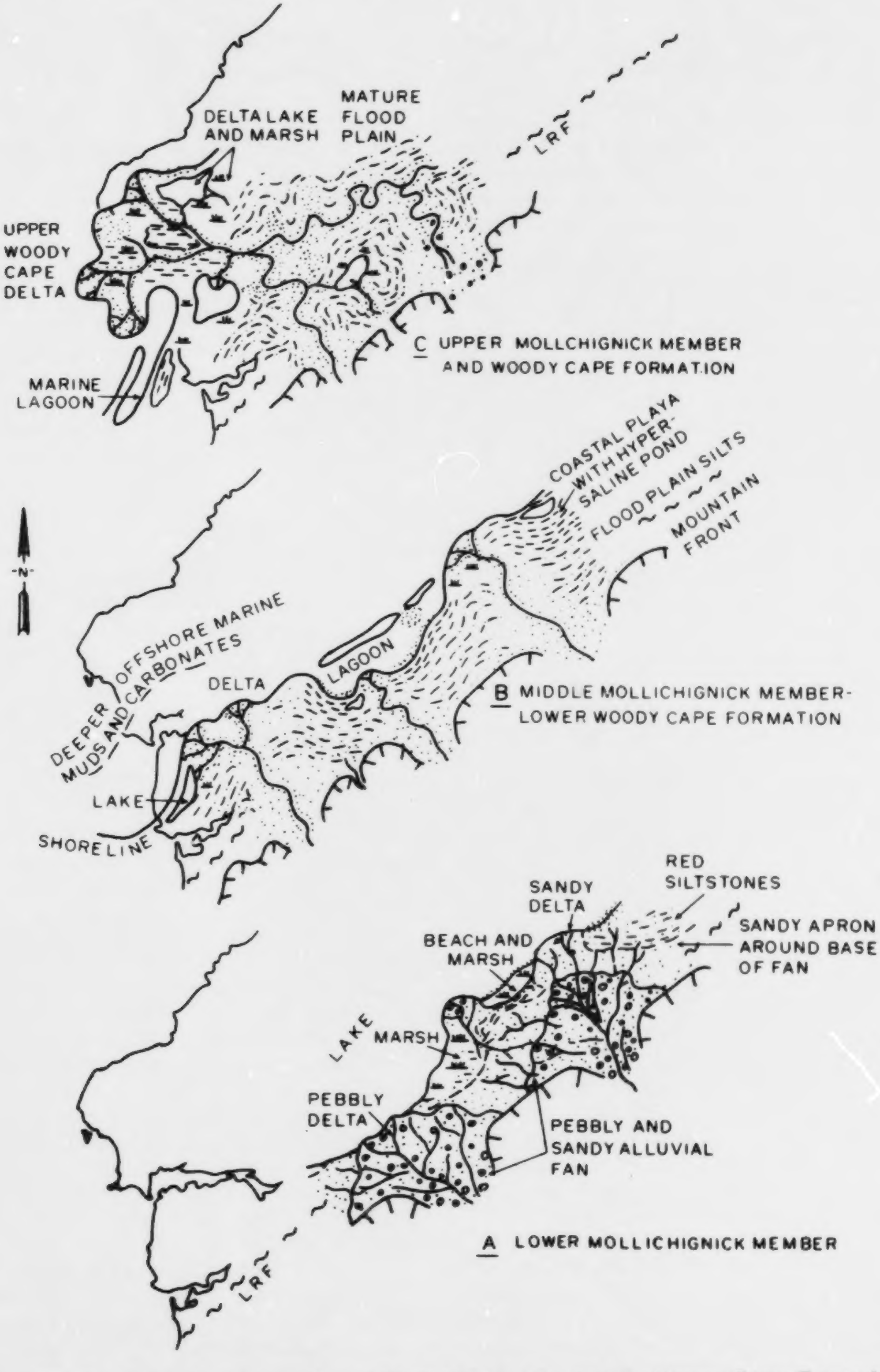

DELTA LAKE AND MARSH
MATURE FLOOD PLAIN
LRF
UPPER WOODY CAPE DELTA
MARINE LAGOON
C UPPER MOLLCHIGNICK MEMBER AND WOODY CAPE FORMATION
COASTAL PLAYA WITH HYPER-SALINE POND
FLOOD PLAIN SILTS
MOUNTAIN FRONT
N
OFFSHORE MARINE CARBONATES
DEEPER MUDS AND
DELTA
LAGOON
LAKE
SHORELINE
B MIDDLE MOLLICHIGNICK MEMBER-LOWER WOODY CAPE FORMATION
RED SILTSTONES
SANDY DELTA
BEACH AND MARSH
SANDY APRON AROUND BASE OF FAN
LAKE
MARSH
PEBBLY DELTA
PEBBLY AND SANDY ALLUVIAL FAN
A LOWER MOLLICHIGNICK MEMBER
LRF

Figure 35: Probable paleogeography of Mollichignick Member, Robinsons River Formation and the Woody Cape Formation in the last stages of deposition of the Codroy Group. Overfall Brook Member is not illustrated.

finer alluvium, possibly in response to tectonic uplift (cf. Steel and Wilson, 1975; Steel et al., 1977; Steel and Aasheim, 1978). Alternatively periods of very intense source area precipitation and flooding (cf. Baker, 1977; Heward, 1978a) could have led to fan channel entrenchment and deposition. Fan channels (cf. Bull 1972; Heward, 1978a) were entrenched, and coarse debris was then funnelled as secondary fan lobes out over the toe of the fan and adjacent alluvial plain. Flash floods on the fan itself reworked sediment previously deposited. Such floods caused sheetwash and turned normally shallow ephemeral streams into sediment-laden floods which deposited the fine sand and mud rapidly from suspension as thin, sheet-like deposits (cf. Hardie et al., 1978) as the streams spread out onto the flood plain.

Besides the coarse and fine products of sheetwash that built up the flood plain in the lower 1,000 m of the member, the flood plain was also periodically traversed by large rivers which deposited thick sandstones and overbank sandstones and siltstones. Lacustrine deposits were also an important element of the flood plain. Shallow lakes were sites of bituminous mud and carbonate deposition with a locally abundant aquatic fauna and flora. Laminated and rippled, micaceous beach sands and fine, micaceous, carbonaceous delta sands were deposited along the lake shorelines where shallow streams entered the lakes. Marsh flats formed in sheltered quiet areas between deltas and became the sites of paludal mud and carbonate deposition and diagenesis. The thickness of the lake deposits (up to 50 m thick) suggests that the lakes existed for long periods and were of quite large dimensions.

The lacustrine deposits are most common in the lower 1,000 m of the member where they lie together with red floodplain siltstones at the base of coarsening-upward megasequences, tens to hundreds of metres thick. They are overlain by coarser micaceous sandstones and pebbly arkoses deposited by sheet-flood and braided streams. These megasequences were probably controlled by higher sedimentation rates on the adjacent Mollichignick alluvial fans and led to sheet-flood and distal fan deposits prograding over the lake deposits (Figure 35A).

Approximately 1200 m above the base of the Mollichignick Member, a flat-lying alluvial plain and coastal playa flat environment developed in this area of the subbasin. Alluvial fan influences upon this flood plain were minor and lakes were apparently absent. Marine flooding occurred on a number of occasions from the west and possibly southwest, where marine deltaic rocks of the Woody Cape Formation were being laid down. Fine siliciclastics and some carbonates were deposited in shallow lagoons and bays. Sandy shorelines formed as marine transgression advanced up to the mountain fronts along the southeastern basin margin (Figure 35B). A fauna of small ostracods and molluscs with fewer small gastropods, inarticulate brachiopods and thin-walled brachiopods suggests brackish marine to slightly hypersaline conditions. Crinoid ossicles in some carbonate and siliclastic beds show, however, that nearly normal marine floodwaters inundated the low-lying plains. Algal flats developed along the edges of the shallow lagoons as they were infilled or when floodwaters were ponded on the adjacent coastal playa flats. Secondary displacive nodular anhydrite was precipitated locally in the carbonates as the lagoons were finally desiccated.

Following the last marine interval, fine alluvial sedimentation continued on a generally stable flood plain (Figure 35C). Thick channel sandstones, probably deposits of low and high sinuosity meandering rivers, crossed the alluvial plain. They flowed southwestward (Figure 32C). Although many of sandstone sequences fine upward, some have coarse grained beds at the top of sandstone sequences similar to modern, coarse grained, meandering river deposits (McGowen and Garner, 1970; Jackson, 1975, 1976). Bankfull thickness of channel sandstones of 5 to 6 m gives maximum channel widths of approximately 60 m (Leeder, 1973) and meander belt widths of about 600 m (Collinson, 1978b). Lenticular and sheet-like crevasse-splay sandstones (lithofacies B and C) and sandstone deposits of Bijou Creek-type (McKee et al., 1967; Miall, 1978) built up the flood plain.

The presence of thick beds of old age and siliceous caliches (Reeves, 1970) occur in overbank deposits associated with these channel sandstones. This indicates that sediment failed to reach interfluvial areas of the flood plain for long periods (Allen, 1974; Leeder, 1975).

Basin instability increased during deposition of the final 280 m of the Mollichignick Member when sheetflood sands and coarse sandy and gravelly braided streams again carried coarse detritus northwestward into the basin. These deposits formed part of a final, upward-coarsening megasequence that culminated in the outbuilding, from the paleo-Long Range highlands, of a major, humid, alluvial fan, the Overfall Brook Member.

Appraisal of the succession in the two members would suggest that two distinct, overall coarsening-upward, basin-fill sequences approximately 1000 m thick infilled the basin. The lower basin-fill sequence was built of a coarsening-upward megasequence that suggests several episodes of source uplift and rapid basinward progradation of alluvial fans into and over lakes on the basin floors. The second basin-fill sequence began with quiet tectonic conditions in the source area which allowed fine sediments to be laid down in a low-lying alluvial and coastal plain. Marginal alluvial fans were generally inactive, pedogenic profiles formed and marine flooding was able to occur. Renewed tectonic activity plus increased precipitation in the mountain source area to the southeast initiated a final phase of alluvial fan outbuilding. This formed a final upward-coarsening sequence that culminated in the well washed arkoses of the Overfall Brook Member.

Woody Cape Formation

Definition and distribution

The Woody Cape Formation is a new name proposed for a succession of green and gray colored mudstones, siltstones and sandstones that outcrop only along coastal exposures from Woodville to Capelin Cove in the Codroy lowlands. The formation is named after Woody Cape and includes strata previously assigned to the Woody Cove and Woody Head beds of Bell (1948). These divisions were based upon the presence of thick sandstones and the absence of carbonates in the upper Woody Head Beds. The succession is, however, continuous with no lithological distinctions possible, so that Bell's subdivision is here discontinued. Bell (1948) logged detailed sections along the cliffs from Woodville to Capelin Cove (Sections B, C and D) and it is implicit that he considered the succession to be conformable. He did not recognize, however, that the faulted succession in Capelin Cove is inverted. The type section of the formation occurs in a steeply dipping, right-way-up sequence located mostly north of Woody Cape but continues to a small cove just south of the cape. It includes beds 48 to 226 of Bell's (1948) section D. The base and top of the section is fault-bounded. The base, which occurs 500 m north of Woody Cape, is downthrown against red beds, gray beds and gypsum of the Codroy Road Formation. The top of the type section, which occurs 100 m south of the cape, is bounded by a high angle fault which separates right-way-up beds from inverted Woody Cape beds farther south.

The outcrop of the formation is limited to the immediate area of Woody Cape and Capelin Cove. Inland, no outcrops have been found, although Hayes and Johnson (1938) made reference to some isolated exposures near Doyles and Upper Ferry. The rock types described, however, are equally common in younger and older formations and, in any case, they could not be located during the present study. Limestones possibly belonging to the formation were also described in a number of exposures along the Little Codroy River (Hayes and Johnson, 1938; Utting, 1966) but they were not visited by the writer.

Thickness

The type section as defined here is approximately 690 m thick.

General lithology

The Woody Cape Formation is predominantly a fine grained sequence of gray, gray-green, blue-gray and black mudstones, siltstone and shales. These are intercalated with green-gray, mica-rich sandstones, gray and black carbonates, and minor red siltstone and sandstone. The succession is characterized by its well bedded, sheet-like geometry in most all lithologies (see Figures 36 and 37 on foldout E; Plates 127, 128 and 130). The mudstones and siltstones/sandstones (lithofacies D and E) comprise at least 60% of the formation and many parts of the succession are monotonous sequences of either structureless mudstone or regularly interbedded mudstone and siltstone.

Fossil- and carbonate-bearing marine shales (lithofacies A) form an important element of the lower 200 m of the formation but marine sequences of thin limestone, bioturbated mudstones and shales occur throughout the Woody Cape Formation. Evidence of subaerial environmental conditions is widespread in the upper 400 m of the formation. Redbeds are most common near the top of the type section. Lenticular channel sandstones (lithofacies F), although uncommon, are interspersed through the formation; they are thickest and most abundant in the middle part of the sequence.

A major coarsening-upward megasequence, 43 m thick (Section A, Figure 37) occurs in the basal 200 m of the type section. It consists of basal fossiliferous marine beds overlain by interbedded and graded mudstone and siltstone/sandstone (lithofacies D) and capped by sheet siltstones and sandstones (lithofacies E). For the first 20 m, the megasequence gradually coarsens upwards but the top is composed of several, thinner coarsening-upward sequences, each 5 m thick, of the gray siliciclastics. Many other thinner coarsening- and fining-upward sequences, <5 m thick, occur throughout the formation.

Eight major lithofacies have been recognised within the Woody Cape Formation. They are A) shale lithofacies plus associated beds; B) massive silty mudstone lithofacies, C) laminated mudstone-siltstone lithofacies, D) interbedded mudstone and siltstone/sandstone lithofacies, E) sheet siltstone and sandstone lithofacies, F) thick sandstone lithofacies, G) red sandstone lithofacies and H) carbonate lithofacies.

(A) SHALE LITHOFACIES PLUS ASSOCIATED BEDS

Description of lithofacies A: Black and gray shales form sequences 3 to 34 m thick in at least three different associations. The first such association is black shale interbedded with dolomitic mudstones. The shales display well developed fissility and are interbedded with dolomitic, fossiliferous mudstone beds, 2-10 cm thick (Plate 125). The latter decrease in abundance upwards and are replaced by fossiliferous limestone concretions 5 cm thick. Fossils, which are generally less

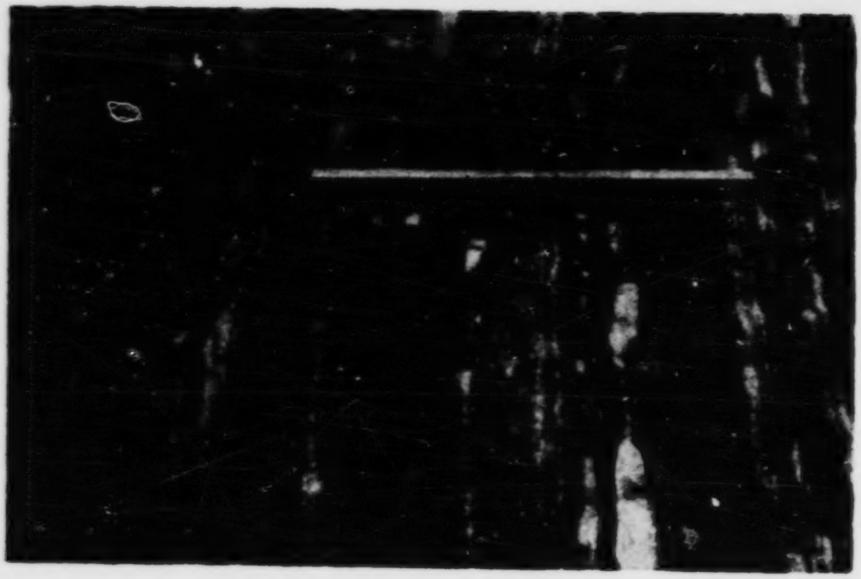


Plate 125: Black shale with limestone laminae, beds and concretions (lithofacies A), base of type section of Woody Cape Formation. Measuring stick 1 m long.

Plate 126: Shales and shaly mudstones intercalated with black lumpy dolomites and limy dolomites, lithofacies A, Woody Cape Formation. Capelin Cove; sequence inverted.

than 0.5 cm in size, include bivalves and brachiopods supplemented by planispiral and high spired gastropods, straight orthocones, trilobite fragments and some possible branchiopods. Shales rich in ostracods, branchiopods and very small bivalves associated with non-fossiliferous shales lie stratigraphically above shales with a diverse marine fauna in Capelin Cove.

A second association lies above the first. It consists of gray shales interbedded at 20-40 cm intervals with 3-10 cm thick lumpy beds of sandy, micaceous and carbonaceous, coarse siltstone and silty mudstones. At the base, the lumpy beds exhibit fine bioturbation. Higher in the section however the siltstones are more evenly bedded and exhibit lamination, ripple cross-lamination and sharp, locally fluted and grooved bases. Here they form 150 cm thick sequences of 20 cm beds separated by a few centimetres of shale. They pass up into rocks of lithofacies D, the sequence as a whole having an upward coarsening aspect (Figure 37, Sections A and D).

The third association consists of interbedded, unfossiliferous shales and 2 to 20 cm, locally 120 cm, lumpy beds of black, unfossiliferous, massive or finely laminated, silty dolomite or limestone (Plate 126). The association occurs above thick channel sandstones (lithofacies F) at the northern point of Woody Cape and above fossiliferous black shales and dolomitic mudstones in Capelin Cove. Some fish scales, halite pseudomorphs and mudcracked surfaces occur locally. Stromatolites occur in some of the black dolomites as well as in yellowish weathering, sandy, dolomitic limestones. Small 2 to 4 cm stromatolite heads generally lack internal structure, but fine tapering fractures filled by white dolomite are common.

Interpretation of lithofacies A: The shale lithofacies was deposited subaqueously in a number of quiet environmental settings.

Quiet offshore marine deposition is suggested by the diverse marine fauna in the shales, calcareous mudstones, and limestone concretions as well as also by lumpy bedding and bioturbation in the associated siltstones of the first association. Sequences in which there is an upwards decrease of carbonate beds and bioturbation but an increase in frequency and thickness of current-deposited siltstones (Figure 37, Section A) are similiar to sequences produced when deltaic sand lobes prograde into an offshore setting (Elliott, 1976a, 1978).

Other sequences containing shales of the first association include one succession in which shales with a restricted dwarf fauna, including branchiopods, overlie shales with a diverse marine fauna. This suggests that the shales were first deposited in an open, fully marine bay which was later restricted, perhaps as distributary sands advanced into the bay or sand bars formed at the mouth of the bay. Consequently, the bay became brackish, as suggested by the restricted dwarf fauna (Bell, 1929, 1948; Heckel, 1972).

The preservation of thin stromatolite beds, halite pseudomorphs and mudcracked horizons and lack of all fauna except some fish scales suggest that the shales and lumpy dolomite of the third association were deposited in low-lying interdistributary areas of the delta plain (Kanes, 1970). The stratigraphic position of these shales and lumpy dolomite, above channel sandstones and/or other shales interpreted as deposits of marine to brackish bays, suggests that they were deposited both adjacent to distributary channels and at the heads of bays. As such, they were probably deposited in shallow, frequently desiccated lagoons, lakes and marshs provided with fine detritus by overbank flooding or marine storm flooding. Similar rock types, interpreted as delta-plain lake deposits, occur in Namurian deltaic strata from Northumberland, England (Leeder, 1974) and the Paleocene Difunta Group of northeastern Mexico (McBride et al., 1975).

(B) MASSIVE SILTY MUDSTONE LITHOFACIES

Description of lithofacies B: This facies consists of deposits, 1 to 8 m thick, of blue-gray, green and red, structureless to thickly bedded (20 to 200 cm), hackly weathering mudstone. Although uncommon, this facies occurs in two sequences 20 m and 42 m thick in the type section and Capelin Cove section, respectively. In both places, they are intercalated with lithofacies C, D, E, and F. Upwards color changes from blue-gray and/or green to red are common within deposits.

Mudcracks, centimetre-size caliche nodules, and thin developments of wavy lamination or ripple and ripple-drift cross-lamination also occur in the mudstones where they are siltier and lie below lithofacies G red sandstones.

Laminae of yellowish weathering dolomite occur in a bedded red siltstone in strata south of and stratigraphically above the thick sandstone at Woody Cape.

Crystals, nodules, deformed lenticular layers, and crystal-lined vugs of strontianite ($SrCo_3$) (identified by Dr. Peter von Bitter, personal communication, 1978) occur in some structureless blue-gray mudstones. Finely laminated structure is disrupted by the strontianite in some beds.

Interpretation of lithofacies B: These thick, structureless mudstones are interpreted as flood plain deposits similar to those described for delta plains (McBride et al., 1975) and alluvial plains (Allen, 1965a). The thickness of structureless beds, some with thin units of ripple bedding or climbing ripple-drift, suggests crevasse flooding (Coleman, 1969) and rapid deposition of abundant mud and silt by ponded floodwaters. Drab to red coloration probably reflects water table changes. A high water table common to low areas of the delta plain promoted drab colors whereas build-up of the flood plain and lowering of the water table allowed oxidation and promoted the formation of red pigment in the fine muds (Friend, 1966; van Houten, 1973; McBride et al., 1975; Braunagel and Stanely, 1977; McPherson, 1980). Exposed surfaces were desiccated and small, pedogenic carbonate concretions formed in the muds. Strontianite probably formed early in the history of the mudstones, possibly diagenetically after celestite (Deer et al., 1974). The stratigraphic position of strontianite-bearing mudstone below fossil-bearing, marine shales suggests that the strontianite formed in mudflats that lay close to the marine environment.

(C) LAMINATED MUDSTONE-SILTSTONE LITHOFACIES

Description of lithofacies C: Interlaminated green-gray, blue-gray and gray siltstones and mudstones comprise this lithofacies. They occur in 20 cm beds or sequences up to 4.5 m thick (Figure 37, Section F). The lamination is flat to microconvoluted, with some small discontinuities and scours filled locally by cross-lamination. Rare to abundant halite pseudomorphs and vugs, 1 - 5 mm in size, occur in some units and locally disrupt the lamination. No mudcracks were observed in the laminite itself but they were noted in one sequence on the bases of interbedded sandstone beds.

Interpretation of lithofacies C: Similar finely laminated mudstones in both the Codroy Road and Robinsons River Formations were interpreted as deposits of quiet water bodies fed by limited quantities of mud and silt. Mudstones of the Woody Cape Formation may have been deposited in shallow, sheltered, offshore settings such as bays (Elliott, 1974b, 1976b, 1978a; Wright, 1978) or shallow ponds or lagoon on the lower delta plain. Halite pseudomorphs suggest that some units were deposited in hypersaline ponds (Leeder, 1974). Mudcracks at the base of interbedded sandstones indicate that many pools on the delta plain were repeatedly desiccated and recharged by overbank flooding.

Plate 127: Coarsening-upward sequence of sheet-like deposits of mudstone, siltstone and silty sandstone, lithofacies D and E, Woody Cape Formation. These deposits are cut into by a channel that is filled by crossbedded and planar laminated sandstone (lithofacies F). The channelled sandstone is in turn overlain by interbedded mudstones and siltstones (lithofacies D) capped by a thick sheet of sandstone composed of climbing ripple-drift with current direction down-dip i.e. southwards. Type section, north of Woody Cape.

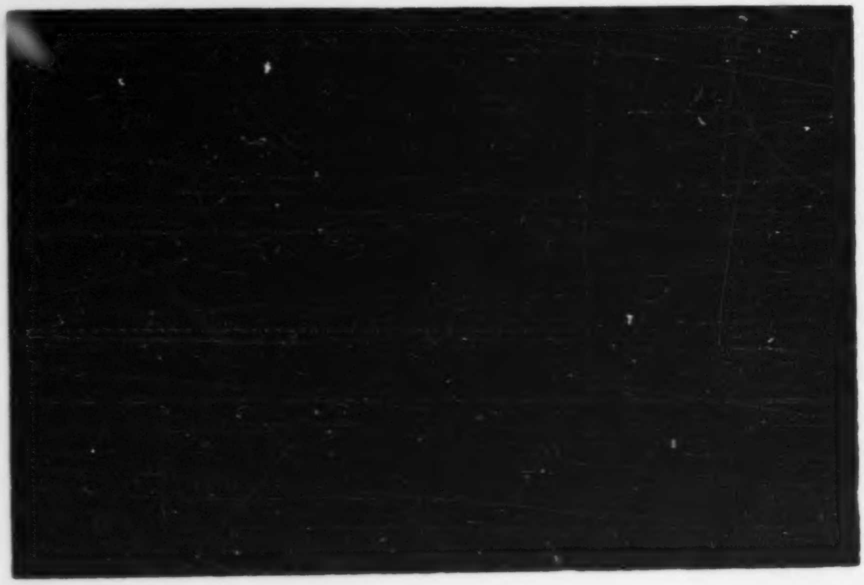


Plate 128: Interbedded siltstones and mudstones of lithofacies D, Woody Cape Formation, Capelin Cove. Middle siltstone bed lies gradationally above mudstones in coarsening upward unit. Beds inverted. Ruler is 1 m long.

(D) INTERBEDDED MUDSTONE-SILTSTONE/ SANDSTONE LITHOFACIES

Description of lithofacies D: This facies consists of regularly interlayered blue-gray mudstones and gray-green siltstones, or, silty, very fine, micaceous and carbonaceous sandstones (Plates 127, 128). The lithologies occur generally in 30 to 150 cm beds that are either sharply interstratified or else fine or coarsen upwards. The facies forms sequences up to 5 m thick.

Most fining-upward beds have sharp, planar to locally erosive bases, some carrying basal sole marks. These beds exhibit planar lamination overlain by ripple, or ripple-drift cross-lamination, or cross-lamination alone. Shale lenses are common in the cross-lamination. The coarse beds grade upwards into structureless mudstones which commonly have bioturbated tops where this facies occurs above marine shales. Sequences composed of fining-upward beds in some instances coarsen upwards into lithofacies E lithologies which show evidence of emergence.

Coarsening-upward beds (Plate 128) consist of massive basal mudstone which gradually becomes siltier and laminated and cross-laminated upwards. It then grades into a coarse cross-laminated, siltstone which has a sharp flat top (Plate 129). Convolution of lamination in the top of the mudstones is common.

Sharply interstratified beds consist of generally structureless mudstones and cross-laminated coarse beds. Mudcracks are common in these interstratified sequences. Most paleoflow directions of ripple-drift in the lithofacies are directed southwards but some beds near the top of coarsening-upward sequences have flow indicators directed to the north.

Interpretation of lithofacies D: The interbedded mudstones and siltstones or silty sandstones of this lithofacies were deposited both subaqueously or subaerially. Bioturbation of tops of mudstone beds, lack of desiccation features in many sections, and stratigraphic position above marine shales support subaqueous deposition for some sections of the facies. Graded siltstone-mudstone beds with sharp locally fluted bases, internal structure consisting of lamination overlain by ripple lamination and then structureless mudstone resemble 'turbidite' deposits possibly laid down by decelerating density underflows.

The sheet-like graded beds overlie basal marine shales within thick coarsening-upward sequences. As such, they are interpreted as deposits of deltas that prograded into an offshore basin (Kelling and George, 1971; Elliott, 1976a). Single beds that gradually coarsen upward as well as thin coarsening-upward sequences of graded beds are interpreted as crevasse splay deposits. These formed in shallow interdistributary bays or delta plain lakes when floodwaters breached the main distributary channels and flooded adjacent interdistributary areas (Elliott, 1974b, 1975, 1976a; Horne et al., 1978). Where these crevasse deposits aggraded above water level, they were desiccated. The reversal of paleocurrent direction in the top bed of some sequences suggests that wave reworking occurred in some deposits after the splay was abandoned (Elliott, 1974a, 1974b, 1975, 1978a; McBride et al., 1975).

Other rocks of this facies were also deposited upon the delta plain. There, they formed sequences of regularly alternating siltstone and mudstone beds characterized by sharp contacts, no apparent trends, and some mudcracked

Plate 129: Ripple cross-laminated, sandy siltstone gradationally overlying cross-laminated silty mudstone of lithofacies D, Woody Cape Formation. The silty mudstones overlie a massive blue-gray mudstone such as that above the sandy siltstone. Type section, just north of Woody Cape. Pen for scale.

Plate 130: Composite unit of sandstone with sheeted geometry, lithofacies E, Woody Cape Formation. Type section, north of Woody Cape. Hammer for scale.

horizons. These rocks suggest that the delta plain was built up by repetitive pulses of overbank flooding.

(E) SHEET SILTSTONE-SANDSTONE LITHOFACIES

Description of lithofacies E: Sheet-like coarse siltstone and fine to very fine sandstone beds form an important element of the formation. They occur as single beds, 10 to 130 cm thick (Plate 127), and in sequences of several beds, several metres thick (Plate 130). The thick sequences either form the upper parts of coarsening-upward sequences completed by scour-based sandstone (lithofacies F) (Plate 127) or fine upward into overlying mudstones. The sandstones of this lithofacies are commonly rich in mica and comminuted fossil plant remains.

Sharp tops and bases characterize the sandstone beds in the facies. Internal structure is generally thin planar stratification and lamination with parting lineations and/or ripple cross-lamination. Ripple cross-lamination may repeatedly underlie planar lamination throughout a single bed. In other beds, cross-lamination is overlain by lamination, and then small crossbeds that contain mudclasts, the bed being completed by ripple cross-lamination. Convolution of internal structure is common.

Current direction of ripple bedding indicates a fairly consistent direction to the west and south in sheet sands of coarsening-upward sequences.

Thick beds composed of either rib-and-furrow cross-lamination with shale drapes or climbing ripple-drift (Plate 127) occur above some coarsening-upward sequences (Figure 37, Section B). Ripple-drift of types A and B (Jopling and Walker, 1968) fill one such bed 127 cm thick. This bed has a slightly erosive base above which the consistent direction of the ripple-drift is 180° azimuth.

Overlying this 127 cm bed is a second coarsening-upward sequence, 4.5 m thick, in which lithofacies D passes up into lithofacies E (Figure 41, Section B). Ripple cross-lamination is consistently directed southwards in this sequence but changes to 018° in a single sheet-sandstone bed, 40 to 76 cm thick, which caps the sequence. The higher sandstone bed has a sharp, flat to scoured base and undulose top. It is composed internally of ripple cross-lamination which locally passes into crossbedding.

Interpretation of lithofacies E: Thick sequences of sheeted current-structured siltstones and sandstones of this lithofacies were deposited at the active front of prograding delta distributary channels. This is supported by their sheet-like geometry, sharp bases and tops, the predominance of ripple cross-lamination and planar lamination, unidirectional paleocurrent vectors and their association within coarsening-upward sequences. Sharp lithological contacts and shale drapes between beds suggest that each bed represents a distinct depositional event. The abundance of rib-and-furrow structure suggests that small linguoid or lunate ripple trains were characteristic of the sand beds (Harms, 1975). Where the sheet sands occur with lithofacies A and D, or C and D in decimetre-thick coarsening-upward megasequences, they are interpreted as fluvially dominated distributary mouth bar deposits (Elliottt, 1976a) or crevasse-splay sand lobes that infilled shallow interdistributary bays or delta plain lakes (Elliott, 1974b). Reworking of the mouth bar by wave action may account for some reversal of paleoflow within the uppermost beds of some sequences.

Single sheet sands composed entirely of climbing ripple-drift and lying within siltstones and mudstones (lithofacies D) probably formed as crevasse-splays that were deposited in interdistributary areas of the delta flood plain.

(F) THICK SANDSTONE LITHOFACIES

Description of lithofacies F: Lithofacies F consists of medium to very fine grained, micaceous and feldspathic, green-gray sandstones in units 2 to 27 m thick. These rocks have channel-scoured bases with relief of several metres. Lenticular bedding, mudstone lenses and plugs, and intraformational conglomerates are common.

Towards the base of the formation, the sandstones are rarely more than 4 m thick. There, they lie erosively at the top of coarsening-upward sequences that also include lithofacies D and E (Figure 37, Section B). Other lithofacies F sandstones lie directly upon bedded, in cases mudcracked, mudstones and siltstones of lithofacies D and locally upon mudstones of lithofacies B. Two variations occur. The first consists generally of ungraded sandstones. They begin with a basal scour and mudclast lag which are overlain by planar stratification with parting lineations and in turn by flat bedding formed of ripple cross-lamination; channels up to 1 m deep filled by large, trough crossbeds downcut into the top of some units.

The second type, in contrast, begins with 20-70 cm lenticular, scour-based beds of sandstone and mudstone that are in turn overlain by sandstones. Whereas the lenticular mudstones, apart from some coal lenses, are mostly structureless, the sandstone lenses display flat to undulose parallel lamination with parting lineations, cross-lamination and rib-and-furrow structures. Large scale trough crossbedding, ripple cross-lamination and some planar lamination characterize the sandstones above the lenticular deposits.

Thick multistory, fining-upward sandstones (Figure 37, Section C) form a third type of deposit which occurs higher in the formation. These consist of large scale trough-crossbeds together with planar stratification and lamination. Lenses and layers of intraformational conglomerate composed of mudclasts and plant debris lie within troughs and along scours at the base of the members. Crossbeds dominate most deposits, and only towards the top of the sandstones does planar stratification with parting lineations and cross-lamination take over. These top beds may be at least 4 m thick. They are commonly rich in mica and fine plant fossil material and include rib-and-furrow structure (Harms, 1975) and climbing ripple-drift of types A and B (Jopling and Walker, 1968). Soft sediment deformation is also common in the lithofacies and is locally truncated by scours.

Directions of ripple-drift, parting lineation, and some crossbeds suggest that current flow was consistently to the south.

Interpretation of lithofacies F: Basal scours, local channel geometry, intraformational conglomerates, trough-crossbeds, planar stratification, and apparent unidirectional paleoflow suggest that these are deposits of river channels.

Where they scour into the tops of coarsening-upward sequences interpreted as distributary mouth bars, the sandstones were probably deposited in distributary channels that supplied a prograding delta lobe. Thicker, multistory, fining-upward deposits, however, more closely resemble sequences typical of meandering river channels (Allen, 1965a and b) and were probably deposited in principal distributary channels higher on the delta plain (McBride et al., 1975). Ripple cross-laminated, fine micaceous sandstones at the top of some deposits are perhaps levee deposits (Coleman and Gagliano, 1965) or fills of abandoned channels (Kelling and George, 1971; Gersib and McCabe, 1981).

Sequences which are associated with delta plain deposits (lithofacies B and D) and are composed of lenticular sandstones and mudstones overlain by trough-crossbedded sandstone were probably deposited by small distributary channels in which the fluvial regime changed with time. Scour and fill structure, horizontal lamination in the lenticular sandstone, and variation of lithology suggest that the lenticular sandstones and mudstones were first laid down by low sinuosity, possibly ephemeral, streams (McBride et al., 1975). The change upward into crossbedded sandstones suggests these channels later became permanent distributaries possibly due to channel switching on the lower delta plain (Kanes, 1970; Donaldson et al., 1970).

(G) RED SANDSTONE LITHOFACIES

Description of lithofacies G: Interbedded within some red silty mudstones are beds of very fine, red sandstone up to 170 cm thick. They lie sharply within or upon the finer redbeds (lithofacies B). Internally, the red sandstones are composed of flat laminations and type A ripple-drift (Jopling and Walker, 1968). The thickest sandstone of this type rests gradationally upon a bed 4 m thick of silty mudstone (lithofacies B). The latter begins with structureless mudstone and is completed by silty mudstones displaying climbing ripple-drift cross-lamination. The red sandstones in turn grade up into gray, laminated, coarse siltstones. Gray sandstones of similar structure also occur in gray silty mudstones within the succession.

Interpretation of lithofacies G: The structure and lithological association suggest that these beds formed by crevasse flooding upon the inner delta flood plain. The sharp but nonerosive base and flat stratification are similar to the Bijou Creek deposits (McKee et al., 1967). Climbing ripple-drift indicates rapid deposition of plentiful sandy sediment carried in suspension (McKee, 1965).

(H) CARBONATE LITHOFACIES

Description of lithofacies H: Carbonate beds composed of lumpy black dolomite and limestone or gray limestone concretions and beds have already been referred to during discussion of lithofacies A. Beds of gray, sandy limestone also occur in the upper part of the section (Figure 37, Section G) at Capelin Cove and above the thick sandstone unit at Woody Cape. These limestones range through lime mudstones to grainstones (Dunham, 1962).

Carbonate beds and concretions within the shale sequences near the base of the Woody Cape Formation vary from lime mudstones to wackestones. The beds are characterized by a system of tapering, irregular fissures that crosscut the depositional fabrics. The lime mudstones typically consist of carbonaceous and pyritic micrite with no fauna except a fine spicular structure, now preserved by clear microspar. Wackestones contain scattered to abundant skeletal grains (Plate 131) that include either all ostracods or a mixed skeletal component including crinoids, gastropods, foraminifera, and whole or fragmented brachiopods, bivalves and ostracods. Hollow-walled, and solid calcispheres are common. A tubular-walled structure similar to *Tubertina* (Mamet, 1970) occurred in one fissure.

Fissures, skeletal fragments and living chambers of organisms were lined by fine radiating calcite which was overlain by brown dusty, radiaxial fibrous mosaic cement (Bathurst, 1975). Most of the skeletal grains except crinoids were recrystallized to or replaced by blocky calcite; traces of original layered structure are visible in some recrystallized fragments. Remaining porosity within the fracture system was closed by coarse blocky calcite.

The grainstones at the top of the Capelin Cove section overlie 95 cm of

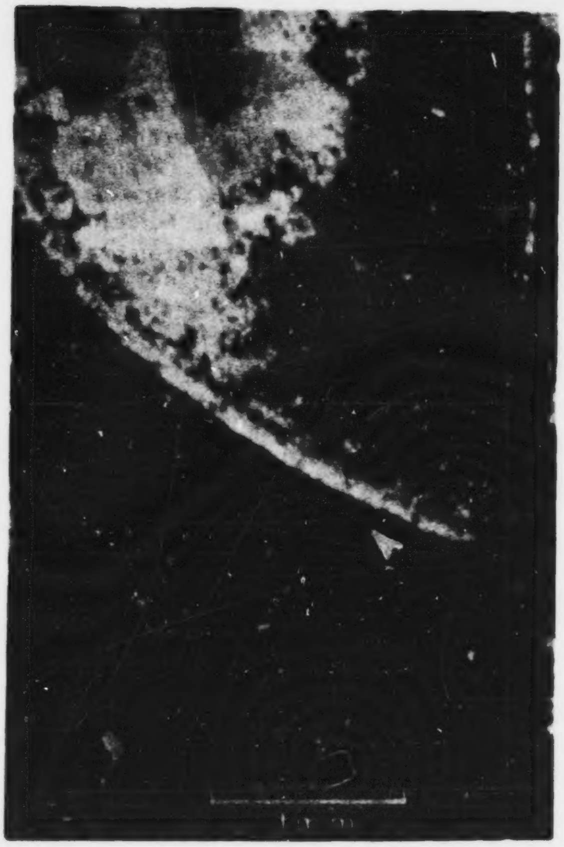


Plate 131: Crinoid and ostracod fragments and a whole brachiopod in skeletal wackestone, lithofacies H, Woody Cape Formation, Capelin Cove. Brachiopod was filled by geopetal mud, pendant cement and blocky spar. Local development of early acicular cement (arrow) was curtailed by accumulation of geopetal mud.

laminated mudstones (lithofacies C) and a gray, wavy bedded, argillaceous micrite bed 1.6 m thick. The grainstone consists of a lower calcirudite bed, 22 cm thick, with an undulose erosive base, overlain by 43 cm of calcarenite. The calcirudite is composed of angular, irregular to platy mudstone, and siltstone and limy intraclasts, 1 cm in size. The clasts are set in a sandy matrix cemented by clear calcite. The limy intraclasts include ostracod-rich and spicule-rich wackestones. Other wackestone intraclasts contain peloids and calcispheres. Silty and mottled lime mudstone intraclasts, dolomitized platy fragments suggesting derivation from laminated lime mudstones, cryptalgal laminite, and grains composed of a radiating fibrous cement are also present. Many dolomitized intraclasts also occur. Some lime mudstone clasts have sand- and micrite-filled burrows. Skeletal allochems include abundant crinoids, some thick-walled bivalves with prismatic and cross-lamellar structure, foraminifera, brachiopod shells, whole or fragmented ostracods, and some scattered vertebrate fragments.

The overlying calcarenite is very coarse grained (Folk, 1962) and has thin, flat to wavy-bedding, and small, westward directed trough crossbeds at the top. Crinoids and algal grains (Plate 132) similar to phylloid algae thalli (Horowitz and Potter, 1971; Bathurst, 1975) dominate the calcarenite. However, some foraminifera, including *Textrataxis* and *Biseriammina windsorensis* (Mamet, 1970), and ooids also occur. Micritic envelopes outline skeletal and algal grains, many of which were subsequently dissolved to produce moldic porosity.

Fine calcite cements rim allochems and many sand grains and clear blocky calcite, 0.05 to 0.1 mm in size, cemented moldic and interparticle porosity. Syntaxial overgrowth of calcite occurred on some crinoid particles.

Interpretation of lithofacies H: Two environmental settings are described in this lithofacies. The first includes limestone beds and nodules, some rich in fossils, that are part of a succession of shales previously interpreted as deposits of a quiet offshore setting. The presence of crinoid ossicles and the abundant shelly fauna in these limestones indicate that normal marine conditions prevailed.

The radial cements that rim and line skeletal grains and chambers are early marine cements (Shinn, 1969; Scholle,

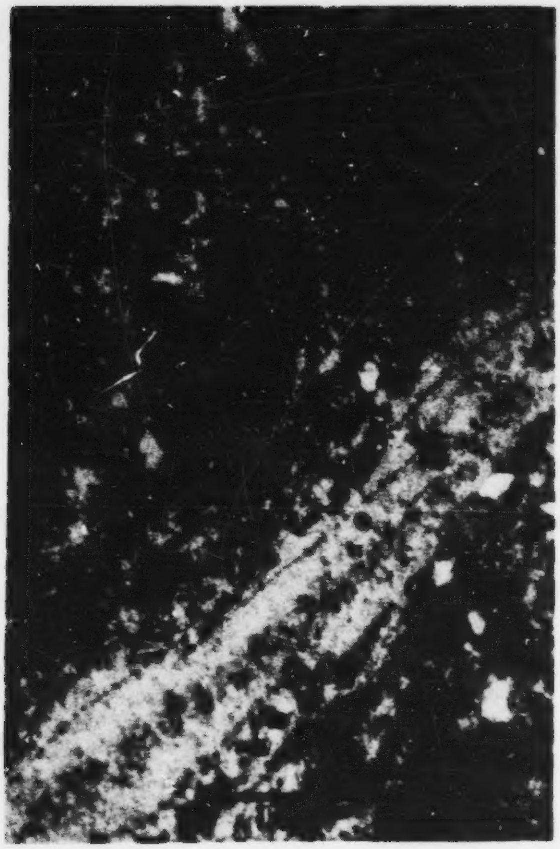


Plate 132: Calcarenite of lithofacies H, Woody Cape Formation, composed of elongate phylloid algal fragments outlined by micrite envelopes, isopachous cement and mosaic spar. The phylloid thalli are mixed elsewhere in the slide with crinoidal fragments and other skeletal and nonskeletal grains. Top of Capelin Cove section, associated with wackestones of plate 131.

1978; Longman, 1980). Similiar cements occur with *"Tubertina"* in fissures in the limy beds and concretions. This suggests that the fractures formed early, as the carbonates accumulated on the sea floor.

A high energy environment was more likely for the grainstones at the top of the Capelin Cove section. The spar-cemented calcarenite and calcirudite lie upon an erosion surface that may be part of a large channel. Clasts derived from silty and burrowed lime mudstones, skeletal wackestones, stromatolites, and partly and completely dolomitized algal mat were mixed with ooids and with shell, crinoid and phylloid algal fragments. This diversity of clasts suggests a wide range of environments in which the original carbonates were deposited, including normal quiet marine lagoons and supratidal algal flats in which dolomitization had occurred. The preservation of many phylloid algal thalli and the angularity of clasts suggest, however, that the transport distance was small. Nevertheless, although the grainstones clearly indicate marine conditions, there is little additional evidence of marine influence in the succession with which the grainstones are associated.

Micritic envelopes around phylloid algae and skeletal grains and radiating fibrous cements (Shinn, 1969; Taylor and Illing, 1969) in some clasts suggest some early marine diagenesis and lithification before and after erosion. Dissolution of shell fragments occurred. Partial infill of algal thalli by fine mosaic spar, syntaxial overgrowth of crinoids fragments and closing of inter- and intraparticle porosity by clear blocky spar suggest that freshwater vadose and phreatic cementation affected the rudite deposits (Scholle, 1978; Longman, 1980) after their deposition.

Paleocurrents in the Woody Cape Formation

Because of the steeply inclined to overturned nature of the succession and lack of bedding plane exposures, paleocurrent direction could be measured accurately only on small scale, ripple cross-lamination and some parting lineations. The distribution of the cross-lamination is polymodal with a strong south-southeast vector which parallels the trend of parting lineations. Some crossbeds from thick, lithofacies F sandstones also gave a south-southeast direction. Nonetheless, some northward directed ripple-lamination and crossbeds occur above or at the top of coarsening upward sequences in beds directly above those with southward directed paleocurrents.

The extent to which directions have been reoriented by block faulting and deformation is not known but caution should be taken in interpretation.

Paleontology, age and correlation of the Woody Cape Formation

Several units of limestone and shale have yielded an abundant fauna in the Woody Cape Formation in Capelin Cove. Fossils are also reported from the type section by Hayes and Johnson (1938), Bell (1948) and, more recently, by McGlynn (personal communication, 1979). McGlynn identified several fossiliferous bands with a diverse brachiopod, bivalve and gastropod fauna (Table 9). Layers rich in small bivalves but lacking other fossils also occur in the fossiliferous shale sections. Ostracods and fish scales were noted in some carbonate beds.

The fauna is both marine and nonmarine. Bell (1948) describes a number of horizons with the branchiopods, *Leaia* and *Pseudotheria* which he suggested were nonmarine. Branchiopods can however also occur in brackish water (Heckel, 1972).

Limestones from the Woody Cape Formation recently yielded conodonts of the *Gnathodus* conodont zone (von Bitter and Plint-Geberl, 1982) including *Apatognathus*, *Mestognathus*, *Gnathodus girtisi*, *G. bilineatus*, *Hindeodus cristulus*, *Spathognathodus campbelli* and *Spathognathodus* n.sp.A.

Animal tracks believed to have been made by amphibians were briefly mentioned by Utting (1966) from some beds north of Woody Cape.

Miospores were recovered (Table 9) from samples collected at Capelin Cove (Utting, personal communication, 1978).

The macro and microfaunas of the Woody Cape Formation have been correlated with those of subzone D and E of the Windsor Group (Hayes and Johnson, 1938; Bell, 1948; McGlynn, personal communication, 1978; von Bitter and Plint-Geberl, 1982). Hayes and Johnson (1938) originally gave a Windsor subzone D age for the basal beds of the formation and this is generally substantiated by recent study of shelly faunas. McGlynn (personal communications, 1978) correlated the fauna with Windsor subzone D and possibly early subzone E and stated that they were similar to the faunas of the Avon, Meander River and Wallace Point limestones of Nova Scotia (Moore and Ryan, 1976). The conodont fauna also gives a late Windsor age typical of Windsor subzones C to E in Nova Scotia (von Bitter and Plint-Geberl, 1982). Miospore assemblages did not yield definitive forms to differentiate an early or late Windsor age (Utting, personal communications, 1978).

Depositional environment of the Woody Cape Formation

A deltaic environment for the Woody Cape Formation is indicated by: (1) the overall drab colored strata (cf. Sutton et al., 1970; Walker and Harms, 1971; Flores, 1972; Mazzullo; 1973; McBride et al., 1975), (2) the paucity of redbeds, (3) the presence of marine strata at the base of and intermittently through the succession and (4) the importance of variable scale, coarsening-upward sequences built up particularly of interbedded mudstones and sheeted siltstones and sandstones and, in some instances, marine shales (see also Bell, 1948). The importance of subaerial features, the scarcity of marine units and the presence of channel sandstones in the upper 400 m implies that much of the formation was deposited however in the subaerial portion of the deltas following an early phase of deposition that included both marine and nonmarine sedimentation (see Figure 35).

Elucidation of the depositional history of the formation is based on only two correlatable sections (Figure 36) which occur north and south of Woody Cape. Basal marine beds indicate a widespread, late Windsor marine incursion (Bell, 1948) which flooded the southwest corner of the subbasin. Fossil- and limestone-bearing shales were laid down over mudcracked and halite-bearing gray mudstones that were deposited upon the lower delta plain. A diverse fauna in the shales suggests near normal salinities and depths sufficient to allow quiet suspension sedimentation. This marine transgression probably reached as far north as the inner Codroy lowlands, where two marine sequences are intercalated in fine flood plain and playa-flat red siltstones and mudstones of the time-equivalent Mollichignick Member of the Robinsons River Formation.

The succession in the two sections of the formation diverge in character above the basal marine shales. Coarsening upward megasequences and sequences composed of sheet-like deposits of mudstones, siltstones and sandstones occur in the lower 200 m of the type section north of Woody Cape. They suggest active deltaic sedimentation gradually overwhelming the marine influence in the northern section. The delta front was built up by sheet-like deposits of graded silt/sand and mud deposited from mud and sand-laden density currents that spread out over the low-lying, open sea floor ahead of the distributary channel mouth. A delta platform was thus built up by processes that suggest a fluvially dominated delta (Galloway, 1975). Rapid aggradation of deposits up to and above sea level resulted in the formation of a delta plain. The thickest coarsening-upward megasequence consists of basal marine shales which pass up through delta front muds and sheet sands and are capped by mudcracked deposits. This megasequence which is 43 m thick suggests a maximum water depth of no greater than 40 m (Klein, 1974). Other upward-coarsening sequences however average 10 m thick. This thickness may be closer to the true depth of marine flooding, especially if one allows for compaction and basin subsidence.

No comparable coarsening-upward sequences occur in the Capelin Cove section. Here, rather, the basal marine fossiliferous shales pass up into nonfossiliferous or sparsely fossiliferous shales with some coarsening-upward beds of mudstone and silt/sandstone. Overall the succession appears to document the gradual infill of a quiet interdistributary bay by mud and periodically by short-lived, sandy crevasse-splays. Faunal changes upward in the shale section from a diverse marine to a small size, restricted fauna indicate that the bay was probably initially affected by the influence of open marine waters. With time however it became closed and brackish as it silted up or was closed off by delta or sand bar construction. In due time, muds of the shallow bays aggraded to and above sea level to become part of the delta plain. The evidence for the delta plain is present in the upper part of both sections through the Woody Cape Formation. Nevertheless, limited marine fossil-bearing beds suggest that a salt water influence did lie in close proximity to the delta plain in the upper part of the formation. The delta plain was crossed by distributary channels. These channels separated a variety of environments in the plain including a complex of shallow bays, brackish and freshwater lagoons, lakes, ponds and marshes (Horne et al., 1978). Immediately adjacent to channels, levees were developed and, higher on the delta plain, floodplain deposits were important.

In the complex of shallow bays, lakes and on parts of the outer delta plain, overbank flooding and crevassing from adjacent channels deposited laminated mudstone (lithofacies C) and coarsening-upward sequences (Elliott, 1974b) of lithofacies D and E. The sequences compare to deposits of delta plain lakes in the Rhone delta (Oomkens, 1970) and to Tournaisian fluvio-deltaic strata of the Lower Border Group, Northern England (Leeder, 1974). The sheltered pools and lakes of the delta plain were, in some instances, gradually desiccated with salt crystals precipitated as the waters became hypersaline. Black shales with lumpy carbonates, thin stromatolites and some salt crystal beds were also deposited in shallow pools and marsh flats similar to those observed on modern and ancient deltas (Kanes, 1970; Leeder, 1974). Structureless mudstones as well as fining-upward sequences of sheet sands and muds were laid down on the delta plain as floodwater overflowed channels and breached levees to form crevasse-splays. Where the delta plain became elevated and drainage improved, oxidation of the mudstones and crevasse-splay sands produced the minor redbeds of the formation.

Distributary channels that crossed the delta plain were probably of varying sizes depending upon their position on the delta. Multistory, fining-upward, channel sandstone deposits found in the upper half of the Woody Cape Formation suggest the presence of large, stable channels on the inner delta plain. The channels were flanked by prominent levees and were filled by thick, fine grained, micaceous, cross-laminated and convoluted sandstones when eventually abandoned. In sections below and between the thick multistory channel deposits, the channel sandstones are thinner and were locally subject to sporadic, ephemeral flow. A decrease in channel size may reflect subdivision of the main channel into several distributaries (McBride et al., 1975) by crevassing or avulsion on the delta plain.

Paleocurrent directions (although not plentiful and possibly reorientated by later deformation) appear to be *dominantly to the south. Some northward* directed paleocurrents, particularly at the top of coarsening-upward sequences, may reflect marine or lacustrine wave activity upon distributary mouth bar-sands after distributary channels were abandoned.

Petrography of the Codroy Group Siliciclastics

Thin sections of 60 siliciclastic rocks from the Codroy Group were examined and include very fine to very coarse grained sandstones, grits and some siltstones that were deposited in both fluvial and marine environments. The rocks are described in three sections. The first consists of siliciclastics of the Ship Cove and Codroy Road Formations which are very fine grained; the second includes sandstones of the Robinsons River Formation that are divided into those from the St. George's Bay lowlands, the Brow Pond lentil and the Codroy lowlands; lastly, sandstones of the Woody Cape Formation are briefly summarized.

The siliciclastics are mostly arkoses and subarkoses. They are generally immature to submature, composed mostly of angular to subrounded grains with variable amounts of matrix or cement. Siliciclastic rocks of the St. George's Bay lowlands are mostly carbonate-cemented, particularly those of marine affinity, whilst those of the Codroy lowlands commonly contain little carbonate cement.

Ship Cove and Codroy Road Formations

Several thin sections of gray, calcareous, coarse siltstones and very fine sandstones and sand laminae in laminated varicolored silty mudstones were examined in these two formations from both lowland areas.

The fine gray siliciclastics vary between well to poorly sorted (Beard and Weyl, 1973). They are composed mostly of quartz, micas, clays and some feldspar. *Grains are mostly angular to subrounded*, quartz overgrowths and sutured "contacts" obscure original grain boundaries.

Quartz is "common" quartz (Folk, 1968) with vacuoles and undulose extinction. Fresh grains of orthoclase, microcline and some plagioclase form less than 10% of the sediment. Flakes and shredded cleavage flakes of muscovite and chlorite are common; some green biotite occurs in the St. George's Bay lowlands but not in the Codroy lowlands.

Rock fragments, polycrystalline quartz and heavy minerals are virtually absent. Rare phyllite grains in halite-bearing gray siltstones occur in the Codroy lowlands. Zircon, tourmaline, rare garnet, magnetite, leucoxene and sphene were noted in sandstones of the Ship Cove Formation on Fischells Brook.

Kaolinite, illite, fine sericite and chlorite, patchy carbonate cement and pyrite and rhombic dolomite crystals form the matrices of the fine siliciclastics.

Robinsons River Formation

Lower Jeffrey's Village Member

Sandstones below the Fischells limestone consist of poorly sorted to well sorted (Beard and Weyl, 1973), very fine to fine sandstones composed of angular to well rounded sand grains. Matrix is virtually absent and the sands were cemented by carbonate which etched grains; silica overgrowths of both quartz and K-feldspar grains are also common.

The sandstones are compositionally arkoses, typified by tabular to angular feldspars which include fresh microcline and fresh to altered microcline-perthite, perthite, plagioclase and orthoclase. Perthites include fine string and stringlet types as well as patchy replacement and interpenetrating types (Alling, 1938). Iron oxides cloud some orthoclases, and sericite and rarely epidote alteration had affected many plagioclase grains before erosion and deposition in the sandstones.

Muscovite, green biotite, and some felted chlorite grains are rare as are rock fragments. The latter, however, do include quartz-plagioclase plutonic grains, mafic volcanics composed of plagioclase microlites set in magnetite-speckled chloritic matrix, and spherulitic and cherty silicic volcanic grains. Phyllites, quartz-muscovite schists and apparently undeformed siltstones are also present.

Quartz grains are mostly vacuole-bearing, 'common' quartz with slight to moderate undulose extinction. Composite quartz is rare; some quartz grains are both unstrained and clear with embayed boundaries suggesting volcanic quartz.

Zircon, tourmaline, garnet, epidote and magnetite compose the detrital heavy minerals.

Upper Jeffrey's Village Member and Highlands Member

Very fine to fine grained red sandstones above the Fischells limestone of the Upper Jeffrey's Village Member generally show less variety than sandstones below the limestone although quartz, feldspars and phyllosilicates are the same. The red sandstones are, however, virtually devoid of lithic grains or detrital heavy minerals; only unaltered feldspars occur.

The detrital suite of coarse red sandstones collected from the Fischells Brook and Flat Bay area is, however, essentially the same as that of sandstones below the Fischells limestone. Feldspars are mostly unaltered although orthoclase may be cloudy due to disseminated iron oxides. Rod perthites and perthitic microclines are common. Volcanic and low grade metamorphic lithic fragments occur and include chloritic mafic volcanic grains, spherulitic and cherty felsic volcanic grains and quartz sericite and sericite-chlorite phyllites.

The quartz mode which includes some composite grains is mostly of "common" quartz of plutonic and vein origin; clear, unstrained quartz grains which retain prismatic crystal shapes and embayments typical of volcanic quartz phenocrysts also occur.

Some laminated sandstones associated with marine carbonates contain a diverse heavy mineral assemblage. This includes zircon, tourmaline, garnet, spinel(?), epidote, sphene, inclusion-rich staurolite and possibly red translucent rutile. Opaque grains include magnetite, leucoxene and a few grains of chromite.

Red sandstones of the Highlands Member type section, although coarser grained and moderately well sorted, show little compositional variation from those of the Jeffrey's Village Member. Predominance of K-feldspar over plagioclase, the general lack of composite quartz and of volcanic and plutonic rock fragments but the continued presence of phyllites and quartz-sericite schists is characteristic. Antigorite rock fragments are also present.

Red sandstones examined from the St. Teresa drill hole and believed to have been deposited in a northeast trending trough, northwest of the Flat Bay anticline, contrast to the sandstones of the Highlands Member type section. They are typically poorly sorted and contain rock fragments, many of which are of plutonic and metamorphic origin. They include phyllites, quartz-muscovite, quartz-muscovite-epidote, and quartz-sericite-fibrolite schists. Grains of quartz and prismatic epidote of possible vein origin, and sheared and foliated plutonic rock fragments also occur. Grains of the latter include undeformed plagioclase porphyroclasts. Other plutonic rock fragments include quartz-microcline granites and unstained and iron-stained serpentinite grains.

Perthitic microcline, microcline, fresh and iron-rich orthoclase and plagioclase enclosing sericite and epidote alteration are common. Quartz grains include slightly to highly strained quartz and some stretched metamorphic quartz also occurs. Large flakes of muscovite and brown biotite and scattered splintery grains of epidote complete the detrital suite.

Brow Pond lentil

Fresh to altered feldspars, plutonic and some metamorphic rock fragments characterize the gritty and coarse grained arkosic sandstones of the Brow Pond lentil. The siliciclastics are mostly free of matrix and cements so that the rock is characterized by good interlocking grain contacts. Red to brown iron oxides coat grain boundaries.

The feldspathic mode of the arkoses consists of fresh microclines and perthites and cloudy iron-rich orthoclases. Plagioclase is fresh or contains variable amounts of sericite alteration. Plagioclase is particularly common in one thin section. Here the grains display coarse to fine albite twinning that allowed determination of an andesine composition for the feldspars. Perthites include string mesoperthites resembling those of Acadian granites of the Lloyds River intrusive suite (Kean, personal communication, 1981). Acid plutonic rock fragments include plagioclase - K - feldspar with myrmekitic quartz, microcline enclosing quartz and twinned plagioclase phenocrysts, quartz-microcline and quartz-plagioclase assemblages; plutonic rock fragments also enclose muscovite flakes. A possible tonalite grain composed of fresh Carlsbad twinned plagioclase and quartz was also noted.

Rock fragments derived from a low grade metamorphic terrain include phyllite, metasiltstones, and chlorite-sericite and quartz-chlorite schists. Phyllosilicates include muscovite, some green-brown biotite and chloritic biotite with strongly anomalous interference colors. Unicrystalline and composite "common" quartz is generally undeformed to slightly strained, typical of plutonic or vein origin.

Mollichignick and Overfall Brook Members

The sandstones of the upper members of the Robinsons River Formation, in the Codroy lowlands, include arkoses and subarkoses. Gray to red sandstones of the Mollichignick Member are frequently argillaceous and micaceous, containing up to 50% mica in some sandstones. The clay matrix which is composed of kaolinite, illite(?) and fine chlorite is mostly masked by iron oxide impregnation. Carbonate cements in intergranular voids are uncommon except in marine sandstones. The sandstones of the Overfall Brook Member are predominantly arkoses, with variable matrix, little cement and poor to well developed grain contacts. Sand grains are invariably angular in both members; some silica overgrowths occur.

Typical of sandstones in the Mollichignick Member is the abundance of strongly strained quartz grains compared to unstrained quartz. Composite quartz grains include stretched, schistose and equigranular recrystallized metamorphic quartz as well as "common" quartz of plutonic and vein origin. Much of the "common" quartz has been strained however and is locally recrystallized.

Feldspars are dominated by microcline and perthites but plagioclase and orthoclase also occur. The microcline which is rare in some sandstones of the Mollichignick Member is invariably fresh. Perthites include rod, stringlet, string, string mesoperthites, interpenetrating and patchy replacement types. Much of the orthoclase is turbid and some are rich in fine iron oxides. Plagioclases are unaltered, cloudy or partly sericitized and some contain myremykitic quartz. Granite rock fragments include quartz-plagioclase± muscovite, quartz-microcline±muscovite and K-feldspar-plagioclase assemblages in which graphic and myrmekitic textures are common.

Metamorphic rock fragments include phyllites and quartz-muscovite and chlorite schists and some quartz or quartz-sericite mylonites. Large mica flakes that consist mostly of muscovite, green biotite and felted and platy chlorite but include some brown to khaki biotites are distributed in the sandstones. Interlayered muscovite and green biotite occurs in some of the detrital flakes. Secondary iron enrichment and staining obscures many of the micas in the Mollichignick Member. Detrital heavy minerals include zircon, schorlite tourmalines, garnets, epidote, sphene and possible cassiterite. Hornblende was noted in the Overfall Brook Member.

Sandstones within the Mollichignick Member northeast of South Branch are supplemented with detritus not seen in 12 thin sections examined from the Overfall Brook Member. In particular, the sandstones contain abundant zoisite, garnets rich in inclusions, grains of fibrolite-muscovite schist and large plagioclases in which there is much sericite and epidote alteration.

Woody Cape Formation

The subarkosic and less commonly arkosic sandstones of the Woody Cape Formation are compositionally very similar to the sandstones of the Mollichignick Member with which they are laterally equivalent. The sandstones are either argillaceous or calcareous, very fine to medium grained arenites composed mostly of angular to subrounded sand grains.

Briefly summarized, abundance of highly strained "common" quartz, of stretched and mylonitic metamorphic quartz, dominance of metamorphic rock fragments of low metamorphic grade, abundance of green biotites and muscovite and importance of fresh microclines and cloudy orthoclase feldspar is similar to the Mollichignick sandstones. Graphic intergrowth of quartz and feldspar was noted but no composite quartz of plutonic origin and plutonic rock fragments were observed, presumably reflecting the generally fine grain size of the sandstone (Blatt and Christie, 1963; Connelly, 1965; Cleary and Connelly, 1971). Heavy minerals include only chips of the ultra-stable minerals zircon, tourmaline and rare garnet

Interpretation of the Petrography of the Codroy Group

The detrital components in sandstones of the Codroy Group point to a catchment area that lay mostly southeast of the Long Range fault. Local variation particularly in the north of the subbasin suggests that a source also lay to the northeast of the subbasin at least during the deposition of sandstones that make up the St. Teresa drill hole.

In the north of the subbasin, sandstones of the Jeffrey's Village Member indicate a source terrain chiefly composed of granites but also containing silicic and basic volcanic rocks as well as some low grade metasedimentary rocks. Granites and less significant granodiorites and tonalites supplied detritus to the Brow Pond lentil in the northeast corner of the subbasin. String mesoperthites compare well to those of granites belonging to the Lloyds River intrusive suite (Kean, personal communication, 1981), which lie directly east of the lentil. These Acadian intrusive rocks are spatially closely associated with silicic volcanics, which also provided some of the pebbles and lithic sand grains to the older members of the Robinsons River Formation in this area.

An abundance of highly strained quartz and rock fragments derived from sheared intrusive and metasedimentary rocks occur in the red sandstones of the St. Teresa drill hole. These components point to a provenance in an upland that was composed mostly of highly deformed, metamorphic rocks, likely the Fleur de Lys Supergroup. A highland ridge is thus postulated to occupy an area between the northeastern extension of the Long Range fault and the Humber Arm allochthon highlands. Remnants of these Fleur de Lys highlands are presently seen west of Grand Lake (Knapp et al., 1979).

In general, detritus in the upper Codroy Group succession of the Codroy lowlands in the south of the subbasin shows marked differences to the Codroy succession in the north around the St. George's lowlands. This is most noticeable in the amount of highly strained quartz, the abundance of green biotite, the presence of a wide variety of feldspars and the occurrence of distinctive metamorphic grains and detrital heavy minerals. A provenance for the Codroy Group in the Codroy lowlands is probably found in the rocks of the nearby Long Range Mountains.

Two distinct alluvial fan sequences occur respectively in the Mollichignick and Overfall Brook Members. The argillaceous, iron pigmented, pebbly sandstones of the Mollichignick Member northeast of South Branch contain dominantly metamorphic pebbles. These sandstones also contain abundant detrital zoisite, inclusion-rich garnets and grains of sillimanite-bearing schists. Clean arkoses of the Overfall Brook Member only 12 km to the southwest, however, are composed mostly of perthites, microclines and granitic rock fragments with metamorphic and mylonitic rock fragments. Pebbles include silicic volcanics.

The detritus in the Mollichignick fan probably came from rocks of a northwest trending shear zone that lies directly opposite the member in the Long Range mountains (Chorlton and Dingwell, 1981; Knight *in* Chorlton and Knight, in press). The shear zone is associated with schists bearing sillimanite, zoisite and inclusion-rich garnets.

The arkosic detritus of the Overfall Brook Member implies the erosion of a dominantly granitic terrain with some silicic volcanic rocks. Recent mapping of the Long Range Mountains (Chorlton and Dingwell, 1981; Brown, 1976), however, indicates that these rock types are not found immediately adjacent to the Long Range fault but some 10-15 km farther southeast. This source terrain supports the earlier conclusions drawn from sedimentary facies in the Robinsons River Formation that the basin-mountain contact in late Codroy times did not coincide with the Long Range fault at least in the area of the Codroy lowlands.

The close proximity of the Codroy Group fan sequences to their source rocks in both the Codroy and St. George's Bay lowlands precludes substantial lateral displacements during or since the deposition of the Robinsons River Formation.

Age and Correlative Deposits of the Codroy Group

The Codroy Group is Late Mississippian in age and is correlated with the Windsor Group of Nova Scotia (Hayes and Johnson, 1938; Bell, 1948; Baird and Cote, 1964) with which it has close stratigraphic and lithological similarities (Table 10).

Both shelly and coral faunas (Bell, 1929), conodonts (Globensky, 1967; Baxter and von Bitter, 1979) and miospores (Utting, 1978, 1980) suggest that the Windsor Group is equivalent to the middle to late Viséan of Europe. Mamet (1970) studying the foraminifera of the Carboniferous of the Maritimes suggested that the Windsor Group was deposited in the late Viséan and earliest Namurian, a possibility also hinted at by Globensky (1967). Other workers, e.g. Benson (1974), suggested that middle and perhaps early Viséan is represented by the thick basal evaporites of the Windsor Group. Neves and Belt (1970) using miospores indicate that the base of the overlying Canso Group in Nova Scotia is late Viséan.

Paleogeography and Tectonic Setting of the Codroy Group

The geologic history of the Codroy Group records combined marine and nonmarine sedimentation in the subbasin. In its general history, it compares broadly to that of the Windsor Group in the Maritime provinces (see Table 10). The Codroy Group commenced with the establishment and maintenance of widespread marine transgression. This dominated depositional environments for at least the basal 1000 m of the group leading to the formation firstly of limestone, and then limestone, evaporites and marine siliciclastics within Windsor subzones A and B. Increasingly, however, nonmarine redbeds gradually overwhelmed the shallow margins of the Windsor Sea (Bell, 1929, 1948) and formed the remaining 3000 to 3500 m of the group (late Windsor subzone B to subzone E). Some marine incursions produced isolated marine units stratigraphically high in the Codroy Group suggesting that the marine environment was never far away. This is most obviously expressed by the Woody Cape Formation and Mollichignick Member in the southwest of the basin. The late Windsor marine incursions (Windsor subzones D and E) were quickly buried beneath renewed fluvial sedimentation that filled the subbasin.

The initial shallow marine transgression which lead to the widespread deposition of basal limestones of the Ship Cove Formation flooded the subbasin from south of the Port au Port ridge to Codroy, apparently overstepping the confines of the older Anguille subbasin. Although contacts appear generally conformable, regional Maritime and global stratigraphic evidence has suggested to Geldsetzer (1978) that a long-lived hiatus of several million years separated the

TABLE 10: Correlation of rock units in the Codroy Group of the Bay St. George Subbasin, western Newfoundland and the Windsor Group, Nova Scotia (based on Boyle, 1983; Shea, 1986; Moore and Ryan, 1976, Giles, 1977; Utting, 1980; Boehner, 1991a)

NOVA SCOTIA		SUBZONE	BAY ST. GEORGE SUBBASIN	
LITHOLOGY	FORMATION		FORMATION	LITHOLOGY
Red siltstones, sandstones, limestones, minor gypsum-anhydrite	GREEN OAKS FORMATION Includes KENNETCOOK, MUSQUEDOIT & WALLACE POINT LIMESTONES	E	ROBINSONS RIVER FORMATION OVERFALL BROOK MEMBER WOODY CAPE FORMATION	Red pebbly arkosic sandstones (345 m) Gray-green mudstones, siltstones, sandstones, black carbonates, black shales (890 m)
	Includes MEANDER RIVER and AVON LIMESTONES	D	MOLLICHIGNICK MEMBER ~ ~ ~ ? ~ ~ ~	Red siltstones, sandstones, conglomerates, minor limestones, some gray beds (2275 m)
	Includes HERBERT RIVER and BROOKLYNN STATION LIMESTONES	C	? HIGHLANDS MEMBER ~ ~ ~ ? ~ ~ ~	Red sandstones siltstones, minor limestone (1200 m +)
Limestones, gypsum-anhydrite, minor salt, siltstones, sandstones	WENTWORTH FORMATION and MILLER CREEK FORMATION inc. MILLER CREEK & MAXNER LIMESTONES MacDONALD ROAD FORMATION	B	JEFFREYS VILLAGE MEMBER	Fine redbeds, limestones, gypsum, fine drab beds, sandstones, salt (1400 - 2000 m)
Red siltstone ± minor gypsum-anhydrite	TENNYCAPE FORMATION CARROL'S CORNER FORMATION	A	CODROY ROAD FORMATION	Black limestones, gypsum or anhydrite
Salt, anhydrite gypsum, limestone dolomite	VINLAND FORMATION STEWIACKE FORMATION			Gray shales, evaporitic gray shales, gypsum, anhydrite, red siltstones and mudstones; some black limestone, possible salt (120 - 245 m)
Laminated argillaceous limestone, algal mounds and shelly bioherms	MACUMBER FORMATION		SHIP COVE FORMATION	Laminated argillaceous limestones (13 - 25 m)

Codroy-Windsor Groups from the underlying Anguille-Horton rocks. This is perhaps reflected in the marked lithification of the Anguille Group when compared to friable Codroy strata. There is, nevertheless, little physical evidence that a major disconformity developed at this contact in the Bay St. George subbasin and a gradational contact on Codroy Island provides support for a conformable, time stratigraphic sequence.

The marine flooding was apparently shallow and gentle, advancing from north to south. The strikingly consistent Ship Cove Formation was deposited mostly on a quiet, low-lying, intertidal algal flat. Its landward margin lay to the south, whilst algal mat flourished in shallow subtidal waters in the north. In the Fischells Brook area, a thicker marine sequence suggests marine conditions had already been established there before the sea transgressed southwards.

Evaporites became important as the marine environment continued during deposition of the Codroy Road Formation (Windsor subzone A and early subzone B). Basin analysis has shown that an elongate arm of the sea became the site of dominantly fine siliciclastic deposition and that this seaway was established between what is now Ship Cove and Fischells Brook. It was flanked to the north by a long-lived evaporitic sabkha, whilst a low-lying, coastal alluvial plain occurred to the south. The plain was periodically inundated by the Windsor sea so that gray shales, siltstones, limestones and sulfates were intercalated with nonmarine redbeds. The limestones were locally rich in marine faunas and locally formed biohermal brachiopod and bryozoan build-ups. It seems that normal marine waters reached the subbasin and marine conditions were maintained for sufficient time to allow firstly biohermal construction by a mature fauna and later marine lithification. Thicker bioherms grew in maximum water depths of 10 - 35 m and rose above the sea floor as suggested by rapid lateral thinning. Gradually increasing hypersalinity killed the organic builders of the bioherms. It also led to the deposition of subaqueous gypsum in shallow marine and nonmarine lagoons, and displacive gypsum in the carbonate and siliciclastic sabkhas. Fine redbeds prograded over the marine evaporites in the south as regression reached its maximum development. At present, it is not clear whether salt was precipitated within this initial phase of evaporite accumulation along with gypsum. The thickness and purity of the Fischells Brook deposit contrasts to the bedded, impure nature of the salts of the Robinsons River and St. Fintan's deposits. This suggests that the Fischells Brook deposit might have accumulated east of the Flat Bay "divide" partly or entirely at the same time that the Codroy Road sabkha evaporites were being laid down on the flanks of the high.

The overall environment of the rocks above the Codroy Road Formation became increasingly saline. Salt accumulated in several subsiding depressions (sinks) that were separated by positive divides or arches in the north of the subbasin. To the south, redbed sedimentation was possibly maintained, although gravity lows near St. Andrew's (Hooker Chemical Corporation, 1971) suggest that a salt basin also occurred in the extreme southeast of the subbasin. The sinks had restricted connections to an arm of the Windsor sea, itself the site of salt deposition in an area now under St. George's Bay. Surrounding the salinas (Figure 39a) lay evaporitic mudflats spotted with hypersaline pools and muddy to sandy alluvial fans. At least one major river discharged into the northeast end of the subbasin, feeding at different times one sink or another as its channel switched direction during severe floods. The once shallow salinas deepened as marine or river flooding occurred and bird's-foot deltas built out into the shallow seas. An unconformity within the Brow Pond lentil in the northeast of the subbasin possibly correlates with this period of salt deposition.

The marine depositional environment gradually returned to near normal salinities in the middle of the Jeffrey's Village Member allowing the deposition of several thin limestone units set between thick, red, sandy alluvial sequences (later part of Windsor subzone B). The succession records a transition in the subbasin as nonmarine terrigenous rocks gradually asserted dominion. Transgression produced shallow seas which were filled by carbonates deposited in algal banks and flats, oolite shoals and beachs, open and restricted lagoons, and an open shelf environment. The seas hosted a diverse to restricted fauna. Marine transgression probably originated from the north or west and included both short- and long-lived events. Marine sequences shoaled upwards and regression followed; redbeds buried the margins of the sea. The regressive terrigenous rocks include fine to coarse red alluvium deposited in coastal playa flats, flood plains, and in ephemeral, braided and less commonly meandering river channels. Pebbly alluvial fans formed near basin margins. Paleoflow was dominantly westward and northwestward from a southeastern mountain source across a narrow alluvial plain to the shallow seas.

Above the Heatherton limestone, a thick sequence of fine red terrigenous sediments was deposited. Red siltstone and shaly siltstone were deposited on a distal alluvial plain and in coastal playa flats. The redbeds then coarsened gradually upwards suggesting uplift of the source areas. Fluvial depositional environments evolved from a distal flood plain supplied mostly by ephemeral streams and some geographically restricted meandering rivers (upper Jeffrey's Village Member) upwards into a flood plain drained by large meandering rivers flowing along the basin axis in the Highlands Member (latest Windsor subzone B into early subzone C). Alluvial fans were still, however, important along the southeast margin of the subbasin during deposition of the Highlands Member.

Restricted and widespread shallow seas flooded the alluvial plain at two intervals near the top of the Jeffrey's Village Member and on two occasions in the Highlands Member. In the Jeffrey's Village Member, these marine bands were immediately overlain by coarse fluviatile sediments. Particularly active fluvial sedimentation occurred in a fault-bounded, northeasterly trending trough northwest of Flat Bay during Highlands Member time.

Nonmarine sedimentation was maintained for much of the remaining Codroy Group (Windsor subzones C to E). Unfortunately the record is now found only in the Codroy area, close to the southeast margin of the basin. Marginal alluvial fans fringed by sandy and silty flood plains flanked lacustrine basins in the earliest stages of the deposition of the Mollichignick Member (Figure 35A).

A stable flood plain, however, developed in the middle of the member and coincided with renewed late advance of the Windsor Sea into the southwest of the subbasin (Figure 35B). Drab colored, offshore, delta front and dominantly delta plain siliciclastic deposits were laid down in the Woody Cape Formation in the southwest. Further north fine redbeds of laterally equivalent Mollichignick Member strata suggest that a low, flat-lying flood plain (Figure 40B) was flooded on three occasions by the late Windsor Sea. Nonmarine conditions regained prominance as uplift of the source area produced an upward coarsening megasequence in the upper beds of the Mollichignick and the overlying Overfall Brook Members. Alluvial fans again actively prograded into the subbasin and coarse sandy detritus reached the flood plain in braided streams and by sheetwash.

Source of detritus supplied to the subbasin during the Codroy Group came from highlands that lay mostly to the southeast of the Long Range fault but also at intervals from the southern end of the Humber Arm allochthon highlands.

Most streams were probably steep-gradient, short-headed types. Fine sandy, deltaic facies associated with the evaporitic sequences of the Jeffrey's Village Member and the basal Ship Cove Formation probably indicate that some larger perennial(?) rivers also existed in the northeast of the area. They possibly originated deeper within mountains of central Newfoundland and hence survived during the most arid period in the history of the subbasin.

Climate affecting the subbasin during the evolution of the Codroy Group was mostly semiarid becoming arid during deposition of the evaporites, particularly the salt. Mature and old age caliches in some nonmarine sequences, calcretes in marine carbonates, redbeds with iron pigment forming early after deposition (van Houten, 1973; McPherson, 1980) and the presence of minor evaporites in redbeds confirm that the climate remained semiarid for deposition of most of the group. Nonetheless, higher precipitation in mountain source areas is indicated by: (1) the presence of large perennial rivers and lakes, (2) the large quantities of terrigenous material deposited in the subbasin and (3) the high sedimentation rates for sections which have only minor caliche development. Lack of caliche together with well washed sands and braided stream structure in the youngest deposits of the Overfall Brook Member imply that the climate became increasingly humid near the end of Codroy history.

The tectonic setting of the subbasin during the Codroy Group influenced the deposition. The main axis of the subbasin during deposition of the lower Codroy Group appears to have shifted northwestward from the axial locus of the Anguille Group to the area that is now beneath St. George's Bay. This may be partly reflected by present day outcrop patterns. It is, however, supported by the available thickness data, facies distribution data and geophysical surveys. The Codroy depositional axis apparently coincided with a persistent northeast trending arm of the Windsor Sea. Sediments at least 5000 m thick were laid down in this trough. Active northeast trending faults generally influenced the distribution of sediments. Positive areas separated this main basin from other smaller depositories during deposition of the Robinsons River Formation (Figure 33). An important trough lay east and southeast of the Flat Bay 'divide' in the lower Robinsons River Formation and probably also in the Codroy Road Formation.

The 2700+ m of upper Codroy strata in the Codroy Lowlands also suggests that a trough formed southeast of the 'Anguille Mountain high' during deposition of the Mollichignick Member.

The overall width of the active Bay St. George subbasin expanded from 30 km in the Anguille Group to at least 45 to 60 km in the Codroy Group. Its shape, however, was no longer a simple linear basin but had a complex configuration of highs and lows (Figure 33). Presence of much thicker successions in different areas of the subbasin and at separate stratigraphic intervals, e.g. saline sinks at base of the Jeffrey's Village Member and the pebbly sandstone-filled trough northwest of Flat Bay in the Highlands Member, suggests that fault movements initiated subsidence in separate areas of the subbasin at different times.

The southeastern margin of the subbasin lay along or just southeast of the Long Range fault. Alluvial fans and lithoclasts derived from the metamorphic and crystalline rocks to the southeast testify that the fault was repeatedly active throughout the subbasin's history. In particular, pebbles of silicic volcanic rocks resembling Silurian-Devonian volcanic rocks of central Newfoundland are present in sedimentary rocks as far south as the Codroy Valley. This implies that the

Topsails Igneous Complex, the Lloyds River intrusive suite and the Windsor Point Group formed part of the upland terrains adjacent to this part of the subbasin.

Allocyclical control governed by the regional tectonic setting was probably the main factor influencing both nonmarine and marine sedimentation. The coarsening upward basin-fill sequence in the upper Jeffrey's Village and Highlands Members and the many coarsening-upward sequences and megasequences that formed the two basin-fill sequences of the Mollichignick and Overfall Brook Members confirm uplift of source areas as a decisive factor in sedimentation. Nevertheless, fining-upward megasequences also occur and thick intervals of fine distal alluvium suggest long periods of basin stability when source areas presumably receded. Uplift may also have affected the climate of the source areas allowing greater precipitation. In general, uplift was followed by renewed generation and progradation of coarse alluvium into the subbasin.

Repeated cyclicity of marine and nonmarine beds in the Codroy Road Formation and in the middle part of the Jeffrey's Village Member also suggest an allocyclic, probable tectonic control for the repeated transgressive-regressive stratigraphy of much of the group. In particular, regressive coarse, pebbly sandstones deposited by braided streams were laid down above transgressive marine units in the Jeffrey's Village Member. This suggests basin subsidence coincided with uplift of adjacent source areas and gave rise to transgression. Subsidence was probably also the most important factor that allowed flooding of saline sinks during deposition of the lower Jeffrey's Village Member. The arid climate of that period, however, perhaps counteracted the effect of uplift around the basin preventing influx of large quantities of detritus.

The broad similarity of the Windsor Group of Nova Scotia and the Codroy Group of Newfoundland implies that the tectonic control of sedimentation in the Bay St. George subbasin relates to a regionally active phenomenon. For example, Geldsetzer (1978, 1979) has suggested that the transgressions which flooded the Maritimes Basin reflect an overall setting below global sea level during the Viséan. However, geological events occurring elsewhere within the global Hercynian system may have been a significant factor controlling the cyclical aspect of the succession. For example, several major transgressions are known to have affected northern Europe at this time (Ramsbottom, 1979). Eustatic sea level rise may have been an additional control of cyclicity in the Maritimes Basin. Such sea level changes respond to variations in volume of land ice, ocean basin capacity, growth of oceanic ridges, sediment accumulation or dessication of isolated basins (Pittman, 1978; Donovan and Jones, 1979).

The Windsor Group dominated by evaporites is generally assumed to underlie much of the center of the Maritimes Basin (Geldsetzer, 1979; Howie, 1979; Howie and Barss, 1975 a and b) but at present little is known about the full suite of rock types and facies there. It is difficult to assess how the Windsor Sea in the Maritimes Basin influenced marginal subbasins, such as the Bay St. George subbasin. For instance, Geldsetzer (1978, 1979) envisaged a large, generally land-locked basin drowned by marine flooding to a depth of hundreds of metres to explain the evaporite sequence in the Maritimes Basin. He did recognize, however, that the onland subbasins were probably shallower and influenced more by their marginal setting. This is certainly true of the Bay St. George subbasin where evaporites and associated siliciclastic facies are clearly of shallow, nearshore to shoreline origin. Fossil-bearing carbonates and bioherms associated with sulfate evaporites and redbeds in the

Codroy Road Formation and shallow water to subaerial facies associated with salt sequences in the lower Jeffrey's Village Member oppose a deep basin origin for the evaporites of the Codroy Group as a whole.

Marine flooding from two distinctly separate sources each with its own salinity may in part account for the alternating normal to hypersaline character of the marine strata in the group. Normal seawater possibly entered the subbasin from a Variscan ocean that lay east of Newfoundland (Jansa et al., 1978; Jansa and Mamet, 1979) along a seaway which is postulated here to have formed around the tip and along the west side of the Great Northern Peninsula. This northern seaway is suggested by facies and faunal distribution in the Ship Cove and Codroy Road Formations and carbonate units of the Jeffrey's Village Member. It is also supported by the Carboniferous limestones of the Port au Port Peninsula which were laid down close to a shoreline after southward transgression of seawater into a paleo-Port au Port bay (McArthur and Knight, 1974). The transgression flooded into the Bay St. George subbasin around the western tip of the Port au Port ridge. This northern passage helps account for the near-normal marine faunas of carbonates and biohermal buildups at the base of the cycles in the Codroy Road Formation. Formation of tidal flat to shallow lagoonal gypsum then accumulated in response to local conditions as regression occurred with the cycles completed by redbeds (cf. Schenk, 1969).

The salt-precipitating phase of the Codroy Group that followed quickly after the Codroy Road sulfate phase may be explained by temporary cut-off of the northern seaway. Saline waters from the Maritimes Basin were then fed from the west along the axis of the subbasin. This spilled over into the sinks where salts were readily precipitated with bittern salts accumulating as the phase continued.

The northern seaway was reopened again in the middle part of the deposition of the Jeffrey's Village Member. The marine waters, fed around the western tip of the Port au Port ridge, flooded the axial zone of the subbasin spilling over into the last vestiges of the saline sinks moderating their salinity. Each succeeding transgression rapidly but quietly advanced over a generally low-lying alluvial plain formed of the associated redbeds. .

The final marine event of the Codroy Group involved the Woody Cape Formation and some beds of the Mollichignick Member (Windsor subzones D and E). The Windsor Sea then flooded only the southwest portion of the subbasin, presumably from the south.

Clearly then, at least two oceanic connections may have existed in the history of the Windsor Sea. Previously, most workers have favoured a seaway to the south of Newfoundland and across Cape Breton (Bell, 1929; Mamet, 1970; Geldsetzer, 1978), although Moore (1967) and Schenk (1969) showed that transgressions advanced into the Minas and Antigonish - Mabou subbasins of Nova Scotia from the north, i.e. from the Maritimes Basin. Although this newly postulated northern seaway had an important influence in the Bay St. George subbasin, the similiarity of stratigraphy (Table 11) between Newfoundland and Nova Scotia suggest that the subbasin was not isolated from the rest of the Maritime area.

Preliminary provenance studies of the various rock units of the Codroy Group suggest that there has been little or no relative lateral displacement of the source terrains and the subbasin. This is most clearly shown in the Codroy lowlands by the distinct detrital suites in the Mollichignick and Overfall Brook alluvial fan sequences of late Codroy age. Sandstones in the north of the subbasin that compose the older members of the Robinsons River Formation also indicate that source mountains lay in geologic terrains that presently surround the north of the subbasin.

Wrench movements have been postulated to control sedimentation during the Anguille Group when the basin appears to have evolved as a pull-apart structure. The increase in width of the basin during Codroy Group deposition, however, suggests that simple pull-apart ceased by early Codroy Group times. Many faults that were active wrenches during the deposition of the Anguille Group became inactive and were buried beneath the Codroy cover. This happened to the Snakes Bight fault and the fault that formed the northwestern and northern margins of the Anguille pull-apart basin. The irregular arrangement of actively subsiding troughs and uplifting arches suggest that wrench movements, however, continued into the earliest depositional phases of the Codroy Group. The fault that formed the northwestern margin of the Anguille pull-apart basin is believed to have straightened and extended northeastward toward the northwest margin of the Steel Mountain anorthosite during the deposition of the Codroy Group. This is supported by troughs filled by thick successions of Codroy strata including evaporites beneath St. George's Bay and northwest of Steel Mountain. The trough beneath St. George's Bay developed south of the southern margin of the Humber Arm allochthon highlands and suggests that the highlands must have shifted northeastwards by the earliest stages of the Codroy Group (i.e. late Tournaisian or early Visean).

The thick sedimentary sequence of Codroy strata north of the Anguille Mountains accumulated in a basin that subsided rapidly after completion of the second pulse of Anguille Group basin pull-apart and infill (Table 3). The thin succession of late Anguille strata postulated to occur beneath the Codroy beds in this area means that basin extension continued after the Anguille pulses of basin pull-apart eased. Rapid subsidence followed during the deposition of the Lower Codroy Group, which aided in producing the notably thick 2000 m+ section found in the north of the subbasin.

The detrital component of the rocks in the Codroy Group, particularly those close to the Long Range fault, suggest that lateral movements on the Long Range fault had stopped by Windsor subzones C to E. Instead vertical uplift occurred upon the fault. Block faulting probably dominated in the subbasin at this time along northeast trending, high angle faults. For example, the steep faults bordering the Indian Head Complex and the Steel Mountain anorthosite were displaced northwest side downwards. Thick Codroy sequences close to the faults together with unconformable relationships on the northwest side of the troughs suggest that the faults produced half-grabens. The narrow trough of Mollichignick and Overfall Brook strata in the Codroy lowlands may also have occupied a half-graben.

In the Deer Lake Basin fluvial and lacustrine sediments infilled a basin that widened northwestward outside the confines of a narrow, faulted depository full of Anguille strata. Here uplift of older terrains also occurred, (Figure 16) as did the thickening of Codroy-equivalent strata into and away from an unconformity along the northwest margin of the basin. It seems that the Visean synsedimentary tectonic framework of the Deer Lake and Bay St. George subbasins are comparable. An extremely thick sequence of basal Deer Lake Group strata near Glide Mountain suggested to Hyde (personal communication, 1982) that some basin pull-apart occurred early in the depositional history of this Windsor equivalent group. The timing of this event matches that postulated for the Codroy Group (Table 3).

PART 4 - BARACHOIS GROUP

Definition and Distribution

The Barachois Group, the youngest rock unit in the subbasin, consists of a thick succession of buff weathering, gray sandstones intercalated with red siltstones and/or gray to black mudstones, shales and some coal beds. A sequence of brown conglomerate and sandstone lying unconformably above pre-Carboniferous basement rocks near Trainvain Brook (McDougall's Brook) in the extreme southeastern part of the subbasin is also included in the group. The conglomerates may, however, belong to the Codroy Group, in particular, to the Mollichignick Member of the Robinsons River Formation.

The Barachois Group was named by Baird and Cote (1964) to include the Searston beds (Bell, 1948; Utting, 1966) of the Codroy Valley and the Barachois Series (Hayes and Johnson, 1938; Baird, 1951) of the St. George's coalfield, St. George's Bay lowlands. The Searston beds were considered to be older than the Barachois Series (Bell, 1948) but it is now generally agreed that the two units form a continuum, the older Searston beds passing transitionally upward into younger strata within the Barachois Series (Bell, 1948; Baird and Cote, 1964; Belt, 1969).

The Searston beds, first named by Bell (1948) for strata of a well exposed coastal section in the Codroy lowlands, are here formally elevated to formation status - the Searston Formation. Knowledge of the succession in the St. George's coalfield is still insufficient to allow subdivision of the Barachois Group in this area. The succession, however, appears to consist of older strata lithologically similar to the Searston Formation and a younger sequence which includes coal beds and is here informally called the upper coal-bearing sequence. Thus the Barachois Group does not conform to the accepted definition of a group (American Association of Petroleum Geologists, 1970). However, since the name has been widely used (Baird and Cote, 1964; Belt, 1968a, 1969; Hacquebard, 1972), its use is continued here.

Rocks of the Barachois Group occupy two main areas of the subbasin. To the south, the Searston Formation outcrops mostly in the southwestern part of the Codroy lowlands, between Stormy Point and Little Codroy River; in the St. George's Bay lowlands, the group occupies the Barachois synclinorium. There are minor occurrences of the group at Coal Brook, Codroy lowlands, within a fault-bounded wedge along the Long Range fault, on the coast south of Trainvain Brook, Codroy lowlands, and along Blanche Brook (Riley, 1962), northwest of Stephenville. Rocks of equivalent age also occur on the north side of the Port au Port Peninsula (Belt, 1969; McArthur, personal communication, 1976). Coal-bearing strata occur on Campbell's Brook near St. Andrew's, Codroy lowlands (Hayes and Johnson, 1938).

The coastal section between the Grand Codroy River and Larkin Point (Figure 38 on foldout F) is designated the type section of the Searston Formation. Immediately north of the Grand Codroy River, the formation is covered by recent estuarine and marine muds and sands. The oldest strata known from the formation are exposed at Stormy Point; there, the base of the formation is faulted along the east trending Stormy Point fault against the older Woody Cape Formation. The top of the formation continues seaward beyond the last beds measured at Larkin Point.

In the Barachois synclinorium, the oldest beds of the group along the western side of the synclinorium are faulted against lower Codroy Group rocks across the Crabbes Brook fault of Riley (1962). No basal or fault contact is exposed along the southeastern limb or southern closure of the synclinorium, but block faulting is extrapolated in the area of Crabbes River (Bell, 1948).

The topmost beds exposed occur in the core of the synclinorium near Joe McKays Brook on Barachois Brook.

Brown conglomerates and sandstones exposed along the shore south of Trainvain Brook (Figure 39) unconformably overlie pre-Carboniferous basement of black to green metagabbro of the Long Range mafic-ultramafic complex (Brown, 1976, 1977). The unconformity strikes approximately 212° and dips 31°W; overlying beds are subparallel, dipping a few degrees less than the unconformity. The metagabbro, which was intruded by small veins and dikes of red granite, felsite and granite pegmatite, is strongly decomposed for about 50 cm beneath the unconformity. The brown siliciclastics are the only known Carboniferous rocks east of the Long Range fault.

Thickness

The thickness of the Searston Formation is uncertain. However, about 2500 m is probable for the formation in the Codroy lowlands. This thickness is estimated by adding the approximate thicknesses of two sections through the unit. The thickness of the lower part of the formation is calculated from a structural cross-section of beds between Stormy Point and the mouth of the Grand Codroy River. A section (Figure 38) of approximately 1830 m measured along the coast from the mouth of the Grand Codroy River south to Larkin Point makes up the thickness of the upper interval of the formation. This thickness of the formation as a whole is considerably greater than the 1500 to 1600 m estimated for the Barachois Group in the St. George's coalfield (Hayes and Johnson, 1938; Fong, personal communication, 1976). The thickness of strata at Blanche Brook is unknown; approximately 92 m of conglomerate and sandstone occurs south of Trainvain Brook in the southeastern part of the subbasin.

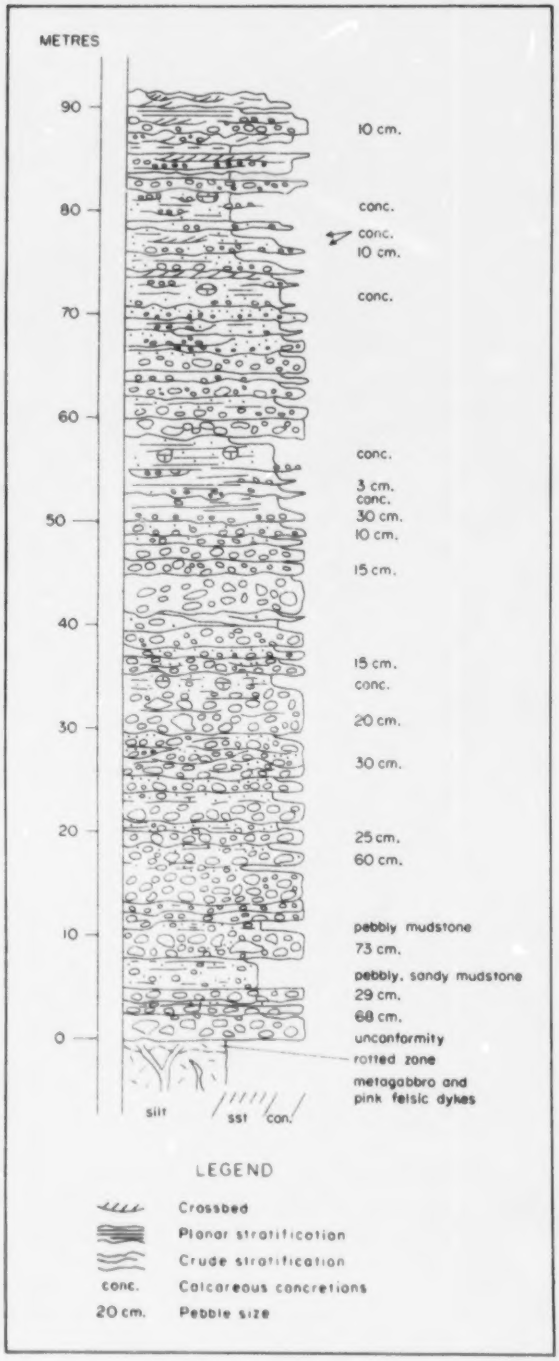

METRES
90
80
70
60
50
40
30
20
10
0
10 cm.
conc.
conc.
10 cm.
conc.
conc.
3 cm.
conc.
30 cm.
10 cm.
15 cm.
15 cm.
conc.
20 cm.
30 cm.
25 cm.
60 cm.
pebbly mudstone
73 cm.
pebbly, sandy mudstone
29 cm.
68 cm.
unconformity
rotted zone
metagabbro and pink felsic dykes
silt
sst
con.
LEGEND
Crossbed
Planar stratification
Crude stratification
conc. Calcareous concretions
20 cm. Pebble size

Figure 39: Stratigraphic section of marginal conglomerate facies in the Searston Formation, cliff section south of Trainvain Brook. The brown-red conglomerates, pebbly sandstones and some siltstones lie unconformably upon mafic rocks of the Long Range mafic - ultramafic igneous complex.

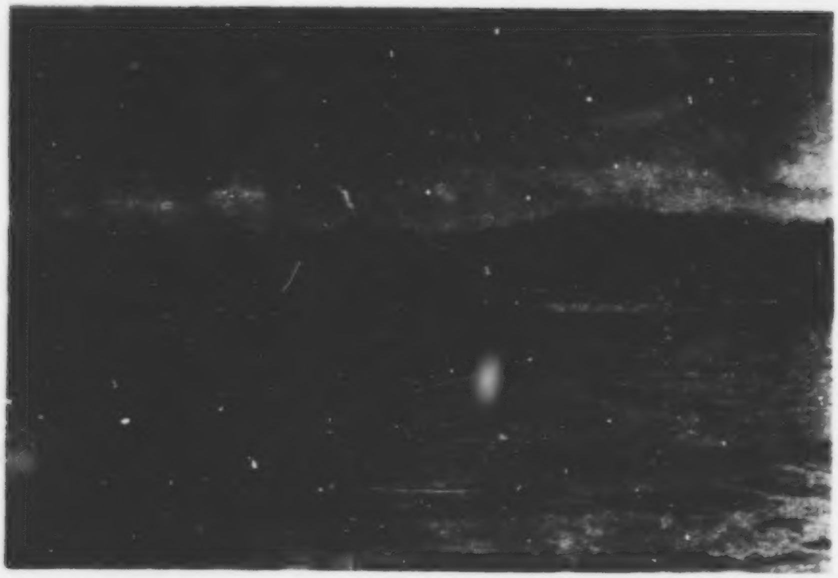


Plate 133: Fining-upward sequences consisting of gray sandstones (lithofacies A) overlain by red siltstones (lithofacies B) in the Searston Formation type section, approximately 3 km south of Kennedy Point. Note multiple channel-fill and dark gray mudstone-shale plug in the channel sandstone. Red siltstones are well bedded.

General Lithology

Lithological descriptions presented here are mostly of the Searston Formation of the Codroy lowlands. The same lithologies, however, also occur in undivided strata of the Barachois Group of the St George's Bay lowlands.

The Searston Formation consists mostly of thick red siltstones and buff weathering, green-gray to red, locally pebbly sandstones that contain some pebble and intraformational conglomerates. Gray to black shales, silty mudstones and muddy siltstones enter the succession approximately 1600 m above the faulted base. The upper coal-bearing sequence is quite similar. It includes gray, pebbly sandstones and conglomerates, red siltstones, and dark colored shales and mudstones interbedded with coal beds at the top of the succession.

Characteristic of both successions is the repetitive development of fining-upward sequences up to 60 m thick (Plate 133). These are composed of coarse and fine members. The coarse members begin with a basal scour overlain by green-gray sandstones that are red colored up section. The sandstones are overlain mostly by red siltstones (Figure 40) or by a combination of red siltstones, gray mudstones and muddy siltstones (Figure 41). Black and dark gray mudstones and shales intercalated with thin beds of gray siltstone or sandstone and several coal beds, however, may also form the fine members of the fining-upward sequences, particularly in the upper coal-bearing sequence.

At least 78 fining-upward sequences occur in the type section of the Searston Formation; several others are exposed near Stormy Point. They range from 10 to 60 m thick in the Searston Formation and up to 30 m thick in the Barachois Group in the Barachois synclinorium (Hayes and Johnson, 1938). The thickest sandstone units are up to 40 m thick and are generally multistory deposits. Fine members are generally less than 30 m thick but some reach 100 m thick in part of the Searston Formation.

The sandstones of the Searston Formation in the Codroy Valley are calcareous subarkoses and arkoses rich in pink to white feldspars and white muscovite. They appear to be consistent throughout the section and exhibit no morphological, compositional or grain size trends up through the section. Associated pebbles, which are mostly about 1 cm and rarely up to 4 cm in diameter, are angular to subrounded, with feldspars retaining prismatic shapes and metamorphic pebbles consisting of tabular or oblate shapes. Pebble lithologies include white, pink and purplish quartz, pink to white feldspar, granite, granite gneiss and other rock fragments. The latter include brown-red, aphanitic, porphyritic and banded silicic volcanics, and jasper. Additional pebble lithologies include white sandstone, green argillite, phyllite, quartz-muscovite and chlorite schists, amphibolite, basalt and gabbro. Similar pebble lithologies occur in the group in the St. George's coalfield.

The thick sandstones display channelling and trough and planar crossbedding as well as small scale current structures. Black and dark gray shale and mudstone plugs, some 2 to 3 m thick and several metres long, are common in the sandstones in parts of the Searston Formation (Plate 133) and are also described in the succession in the St. George's coalfield by Hayes and Johnson (1938). Fine members are dominantly structureless, except for mud cracks, plant rootlets, caliche and, locally in gray beds, ferruginous nodules. Thin sheet and lensoid sandstones, ripple-marked sandstones and some intraformational conglomerates also occur in the fine members. Red lithologies comprise fine members of the sequences in the lower 1600 m of the Searston Formation type section but drab colored siltstones and mudstones 1-7 m thick are intercalated with the red siltstones in the fine member above this level.

In the coastal section south of Trainvain Brook, sedimentary rocks unconformably overlying older basement (Plate 141) consist of brown-red, argillaceous and micaceous, pebble to cobble conglomerates, pebbly sandstones and minor brown siltstones. Pebbles and cobbles of coarse red granite, white granite, coarse gray tonalite with opalescent quartz, porphyritic granite with large pink feldspar phenocrysts, granite gneiss, mafic gneiss, mylonite, metagabbro and light green actinolite gneiss are the main clasts in the conglomerates. Some clasts of decomposed metagabbro similar to rotted metagabbro lying beneath the unconformity also occur. Many of the clasts have shapes that suggest their form was joint controlled.

Description of lithofacies

Six facies are defined within the Barachois Group. They are (A) thick sandstone; (B) red siltstone; (C) gray to black mudstone and shale; (D) coarsening-upward gray shale to sandstone; (E) coal; and (F) brown conglomerate and sandstone.

(A) THICK SANDSTONE LITHOFACIES

Description of lithofacies A: Thick green-gray sandstones form at least 50% of the Searston Formation. They are generally characterized by an upward decrease of grain size and scale of sedimentary structures and a rapid change to red coloration in the top beds. Grain size grades from medium or very coarse at the base to very fine or medium at the top.

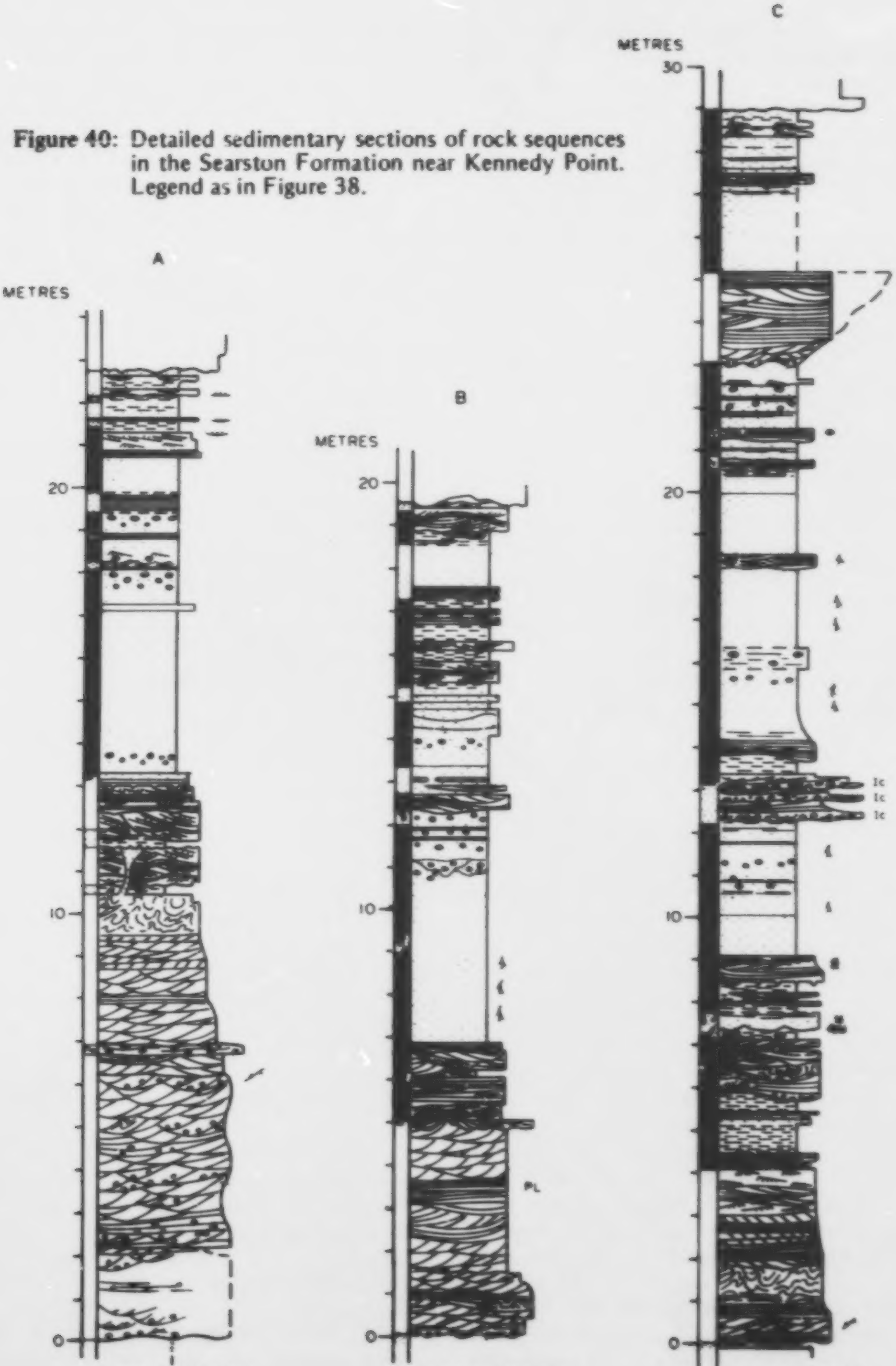
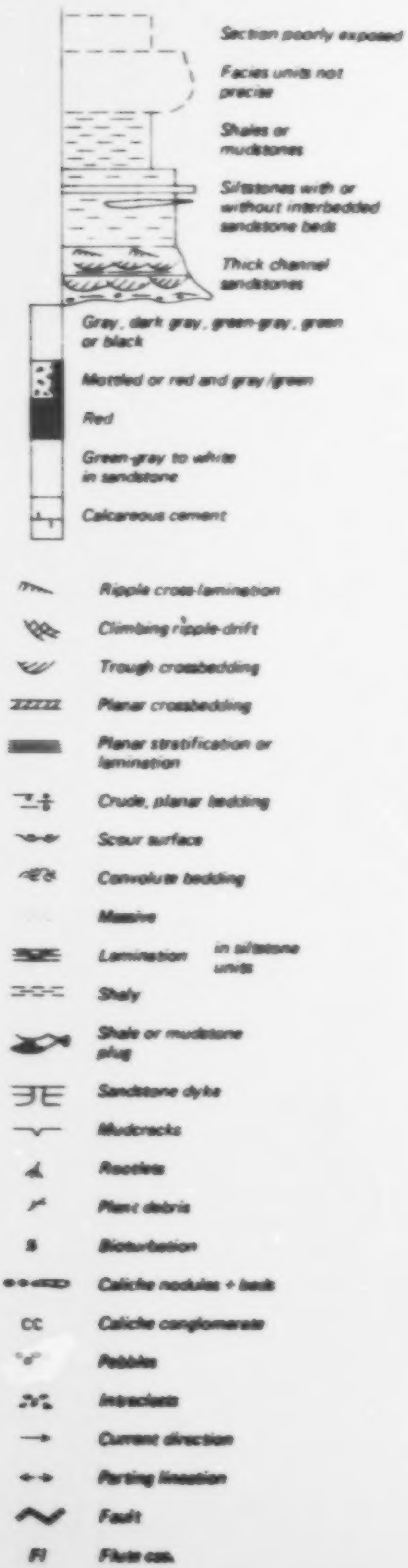

C
METRES
30
20
10
0
A
METRES
20
10
0
B
METRES
20
10
0
PL
Ic
Ic
Ic
Shale/ Mudstone
Shale/ Mudstone
Shale/ Mudstone

Figure 40: Detailed sedimentary sections of rock sequences in the Searston Formation near Kennedy Point. Legend as in Figure 38.

LEGEND for Figure 40


Section poorly exposed
Facies units not precise
Shales or mudstones
Siltstones with or without interbedded sandstone beds
Thick channel sandstones
Gray, dark gray, green-gray, green or black
Mottled or red and gray/green
Red
Green-gray to white in sandstone
Calcareous cement
Ripple cross-lamination
Climbing ripple-drift
Trough crossbedding
Planar crossbedding
Planar stratification or lamination
Crude, planar bedding
Scour surface
Convolute bedding
Massive
Lamination
in siltstone units
Shaly
Shale or mudstone plug
Sandstone dyke
Mudcracks
Rootlets
Plant debris
Bioturbation
Caliche nodules + beds
CC
Caliche conglomerate
Pebbles
Intraclasts
Current direction
Parting lineation
Fault
Fl
Flute cas.

The basal contacts are characterized by well marked, irregular, smooth or undulose scours with relief of 1 to 3 m (Plate 134). Some fine units also contain channel cut-banks (Plates 133 and 134). The scours are overlain by poorly sorted, mostly intraformational conglomerates or very coarse sandstones, 30 to 150 cm thick. These sandstones are either structureless, crossbedded (Plate 135), or display vague horizontal, often lenticular, bedding. Coalified plant remains (some tens of centimetres long), drab colored mudstone and siltstone intraclasts 1 cm in diameter, mudstone blocks up to 100 cm by 30 cm in size, and caliche pebbles mixed with extrabasinal pebbles are common in the intraformational conglomerates.

Trough crossbedding of varying sizes is the most common sedimentary structure in the other sandstones of the members. The crossbeds are mostly 10 to 20 cm thick, up to 100 cm wide, and more than 100 cm long; foresets are generally composed of leafy lamination. Thicker sets up to 120 cm thick have foreset laminations 1 to 3 cm thick. Planar thin stratification and lamination with parting lineations are not common but occur in the sandstones at Northwest Cove. There, they occur near both the base and the top of the sandstones, especially near channel margins (Figure 41). Convolution of crossbeds is common. Planar cross-stratification also occurs toward the top of many sandstone units. These units may consist of several 5 to 8 cm thick cosets of fine sandstone above laterally extensive planar scours. Alternatively, single or multiple large sets up to 40 cm thick are composed of pebbly or gritty coarse sandstones. The pebbly coarse sandstones, however, may also be trough crossbedded or crudely horizontally bedded with thin gravel lenses. They are commonly cemented by coarse white calcite.

Red, very fine grained, micaceous sandstones generally form the top of the sandstone units. These are mostly 50 to

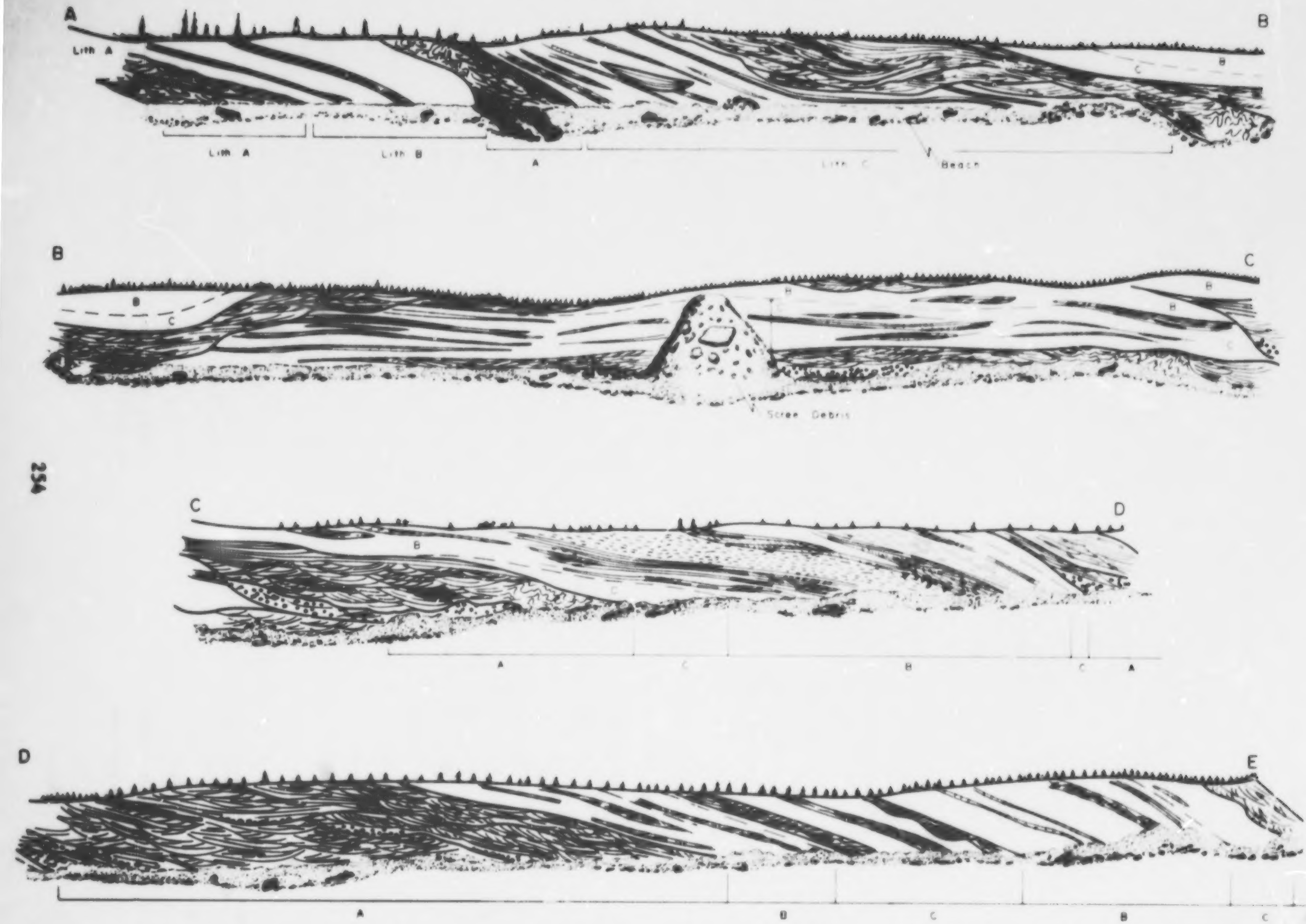

A
B
Lith A
B
C
Lith A
Lith B
A
Lith C
Beach
B
C
B
C
B
B
B
C
Scree Debris
C
D
B
C
A
C
B
C
A
D
E
A
B
C
B
C
A

Figure 41: Notebook sketches of cliff section in the Searston Formation at Northwest Cove. Thick channel-bound sandstones (lithofacies A) cut into red siltstone (lithofacies B) and gray-green silty mudstone (lithofacies C). Horizontal distance approximately 360 m. Cliff height approximately 10 m. Symbols as in Figure 38 and 40.

Plate 134: Thick gray sandstone (lithofacies A) in the Searston Formations at Northwest Cove. The sandstone lies within a channel that cuts down into bedded green-gray mudstones and thin sandstone beds of lithofacies C.

Plate 135: Crossbedded grit lying just above base of thick channel sandstone unit, lithofacies A, Searston Formation in Northwest Cove. Grit is composed of gray shale intraclasts and some small pebbles. Platy bedded sandstones separate the grit from the basal channel scour.

150 cm thick and structurally complex (Figure 40A). Sedimentary structures are dominated by ripple cross-lamination with rib-and-furrow structure (Harms, 1975). Other structures include small trough and planar crossbeds, climbing ripple-drift of types A and B (Jopling and Walker, 1968), parallel lamination, and both planar inclined and scoop-shaped scours, including channels 70 cm deep (Plate 136). Changes of paleoflow direction occur across many of the scours in these top beds. Mudcracked shale partings and layers, quicksand and water-escape structures (Figure 40A), partial disruption of structure by fine downward-projecting rootlet systems, and surface trails and tubular burrows 0.5 cm in diameter are also common. Some of the trails are 1 cm wide, straight, and constructed of alternating lobes (Plate 137).

Both planar cross-stratified sandstones and fine red sandstone may be absent from the top of some sandstone members.

The thickest sandstones consist of multistory deposits internally divided by a number of major scour surfaces, each overlain by pebbly sandstones and trough crossbedded sandstones 1 to 5 m thick. Direction of paleoflow in crossbeds changes across the scours. Extensive lateral exposure of thick sandstones in Northwest Cove (Figure 41) shows that scour surfaces are shingled in the direction of point-bar migration. The scours are not even, but tend to change inclination from almost flat near channel margins to steeply inclined and undulose towards channel axes. The scour surfaces are analogous to epsilon crossbedding of Allen (1963).

Thick channel-sandstone deposits of the upper half of the Searston Formation contain abundant beds, lenses and plugs of black shale and mudstone (Plate 133).

Current directions collected from crossbeds generally give bimodal paleocurrent distributions with modes to the west and northwest (Figure 38).

Interpretation of lithofacies A: The thick sandstone lithofacies has characteristics that conform to those generally attributed to deposits of river channels (Allen, 1965a, 1970a; Visher, 1972; Walker, 1979a). These include (1) basal scours including channel shape and cut bank margins, (2) basal coarse pebbly and intraformational conglomerates, (3) abundant crossbedding and (4) fine red sandstones at the top of members. The upward fining of grain size and decrease in scale of sedimentary structures in the sandstones and the bimodal paleocurrent distributions suggest that they compare to classical fining-upward sequences of meandering channels (Allen, 1964a, 1965a, 1965b, 1970; Collinson, 1978; Walker, 1979a) that formed due to channel erosion and lateral accretion on point bars during migration of the river channel. Vertical changes of sedimentary structure and grain size in these sequences were caused by the gradual changes of flow velocity and water depth as the point bar accreted into the channel thalweg. Structureless, crudely stratified or crossbedded, pebbly and intraclastic coarse sands accumulated as lag deposits and at the base of point bars in the deepest parts of channels (Allen, 1965a; Harms and Fahnestock, 1965; Walker, 1979a). The volumetrically important trough crossbedded sandstones formed in large megaripples that migrated over the surface of the point bar under flow conditions typical of the lower flow regime (Simons et al., 1965; Harms, 1975; Southard, 1975). Infrequently, flow conditions entered the upper flow regime because of increase in stream velocity or decrease in water depth. At such times, planar stratification with parting lineations was developed on the point bar. Large and small, planar crossbedded, coarse and fine grained sandstones that occur toward the top of some members may have been deposited as chute bars downstream from chutes that crossed the upper surface of the point bar (McGowen and Garner, 1970; Jackson, 1976). Oxidized, micaceous, fine grained sandstones at the top were deposited in shallow water that flowed at low

Plate 136: Large "chute?" channel that cuts through ripple cross-laminated, micaceous, gray, fine grained sandstones at top of a channel sandstone unit, Lithofacies A, Searston Formation, Kennedy Point. Structures in the channel-fill sandstones consist of both crossbedding and ripple cross-lamination.

Plate 137: Trace fossils on a slab of gray sandstone at top of thick channel sandstone unit. Tear-shaped lobes (arrow) alternate from side to side in the trail. Searston Formation near O'Quinns Farm.

velocities over the top of the point bar. Small scale cross-laminations generated by migration of small current ripples are the main structures of the latter. Commonly, these rocks were populated by plants and possibly insects, the latter creating the burrows and the crawling trails.

Thicker, multistory sandstones, composed of several scour-based sequences of crossbedded sandstone, suggest that some meander belts were stabilized for long periods. Thick dark shale and mudstone plugs in some channels indicate meander cut-offs were common. Early pedogenic processes or shallow groundwater movements through the sand after the abandonment of meander belts possibly led to early calcitic cementation of the coarse grained sandstone near the top of many sandstone members. Major channel abandonment caused by avulsion may have occurred often and is probably preserved in the rock record where channel sandstones are overlain abruptly by thick floodplain deposits.

Solitary fining-upward sequences (i.e. single-story) probably preserve bankfull depth of channels. They vary in thickness between 4 and 7 m. This suggests a channel approximately 40 to 80 m wide (Leeder, 1973) and a meander belt 400 to 700 m wide (Collinson, 1978b). Some sandstones, up to 13 m thick, indicate channel and meander belt widths of up to 140 m and 1300 m, respectively.

(B) RED SILTSTONE LITHOFACIES

Description of lithofacies B: This lithofacies comprises up to 35% of the Searston Formation (Figure 38) and is composed of red siltstones interbedded with thin red sandstones and intraformational conglomerates. It is the second major lithofacies in the succession and consists of units 2 to 40 m and exceptionally 100 m thick.

Brown-red siltstone is the major lithology. Some layers of green, green-gray, dark gray and blue-gray muddy siltstone, and rare green, black or red waxy mudstones also occur. The brown-red siltstones are well to poorly bedded (Plate 133), with bedding planes spaced at 30 to 200 cm intervals. Caliche nodules less than 1 cm in size, mudcracks, plant rootlets shown by carbon streaks or by red or green coloration, and indistinct, mudcracked or bioturbated laminated siltstone layers, 1 mm to 3 cm thick, occur in the siltstones. In the upper 900 m of the Searston Formation, there are micaceous siltstones which display a weak undulating fissility (Figure 41). There are also carbonate-cemented beds, 6 to 12 cm thick, of laminated sandy siltstone.

Lenses and beds, 10 to 90 cm thick, of very fine to coarse grained sandstones rich in red mudchips are interbedded at intervals in the centre and toward the top of the red siltstones. Erosive or nonerosive mudcracked bases overlain by single or multiple sets of small and large, 4 to 10 cm, trough crossbeds, some planar cross-stratification, planar lamination generally without parting lineations, and ripple cross-lamination characterize the sandstones. Sheet-like sandstones composed of flat, thin stratification with parting lineations and/or ripple cross-lamination also occur.

Lenticular, scour-based, intraformational conglomerates or pebbly sandstones, 10 to 30 cm thick, are also common in the middle of the red siltstone. These are composed of red mudchips and caliche pebbles deposited in trough crossbeds.

Interpretation of lithofacies B: The bedded, structureless, red siltstones are vertical accretion deposits of river flood plains (Allen, 1964a, 1965a, 1965b; Collinson, 1978a) deposited

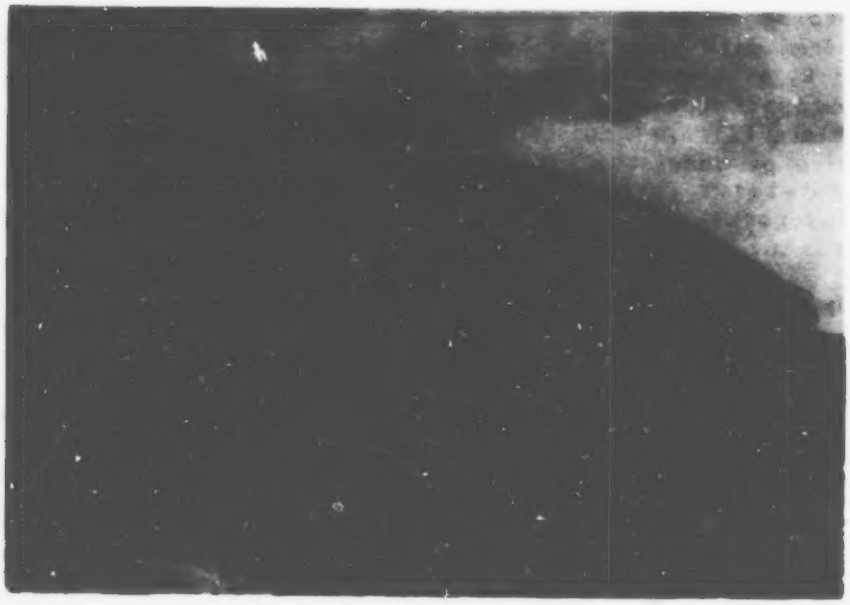


Plate 138: Lithofacies B and C in the Searston Formation at Northwest Cove. Green-gray silty mudstones with thin sandstones (lithofacies C) at base of the cliff are overlain by red siltstones (lithofacies B). Gray sandstones (lithofacies A) lie above scoop-shaped channel scours that erode into the underlying red siltstones.

mainly by flooding from the river channels. Active sedimentation is suggested by lack of thick caliche deposits, although pedogenic processes allowed the formation of small caliche nodules (Allen, 1974; Leeder, 1975). Small stream channels in the flood plains reworked the fine alluvium and nodular caliche into lenticular deposits of caliche conglomerate and lensoid, scour-based, crossbedded sandstone beds. Sheet-like sandstones rich in flat stratification and ripple cross-lamination, and with nonerosive mudcracked bases, probably represent crevasse splay deposits (McKee et al., 1967).

Similar, structureless, drab colored siltstones that have gradational contacts with the red siltstones are indicative of depressions in the flood plain in which sediments remained water-saturated and unoxidised.

(C) GRAY TO BLACK MUDSTONE SHALE LITHOFACIES

Description of lithofacies C: This lithofacies includes a variety of lithologies in units 1 to 7 m thick. It includes dark gray to green-gray mudstones and shales and thin sheet-like beds of coarse gray siltstones and very fine sandstones. It is common in the upper 900 m of the Searston Formation and is associated with coal beds in the upper coal-bearing sequence (Hayes and Johnson, 1938).

In the Searston Formation, this lithofacies occurs most commonly immediately above and below the sandstone members. It is usually intercalated with, or pinches out laterally within, lithofacies B redbeds.

In the Searston Formation, major units of green-gray, silty micaceous mudstones with some thin shales consist of beds 20 to 30 cm thick. These units are interbedded with many thin beds, 5 to 40 cm thick, of coarse, micaceous and carbonaceous siltstone or very fine sandstone (Plate 138). The mudstones are either massive or consist of laminated and structureless layers. Caliche nodules, mudcracks and carbonaceous plant detritus are common.

The sheet-like sandstones and siltstones, which are laterally continuous for 30 to 50 m and locally pass into lithofacies A sandstones, are hard and indurated. They have sharp, planar to locally erosive bases with some groove and flute casts as well as load casts and flame structures. The sandstones are structureless or thinly bedded and planar laminated, with a sharp flat top. In thicker beds, the flat bedding is overlain by ripple cross-lamination, including rib-and-furrow structure. Rare, lensoid, crossbedded or laminated sandstones occur within scours in the mudstones.

Mudcracks, plant fragments and ferruginous nodules also occur in the shales and mudstones of the upper coal-bearing sequence in the St. George's coalfield. Interbedded sheet sandstones are commonly micaceous and contain red shale clasts, ripple-marks, cross-lamination and abundant plant fragments.

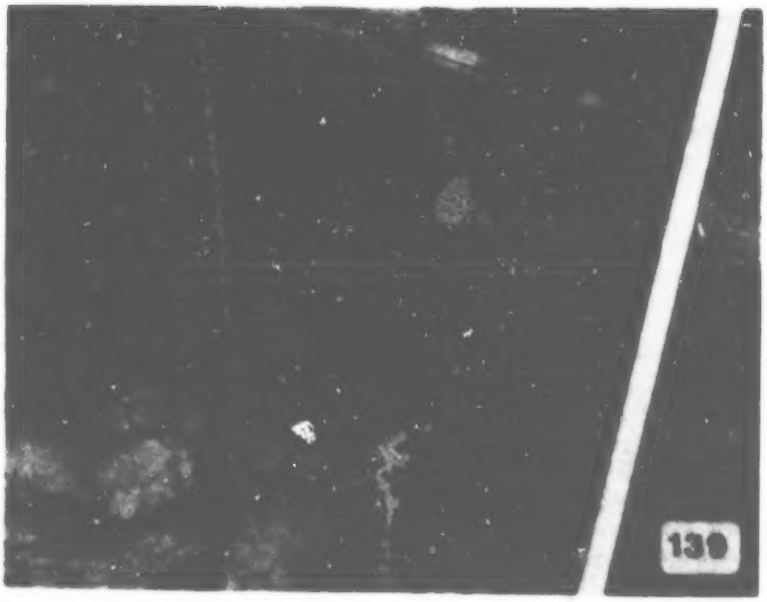
Interpretation of lithofacies C: A quiet backswamp environment typified by marshy mudflats and shallow ponds and lakes close to main river channels is postulated for the gray deposits of lithofacies C (Horne et al., 1978). This is supported by the abundance of plant material and the fine grain size, drab color and extensive sheet-like geometry of coarser beds, some of which grade into channel sandstones. The lack of red color suggests a high water table and saturation of the muds. Flooding from river channels contributed fine muds to the backswamp; sheets of silts and fine sands were periodically spread over the backswamp flats to form crevasse-splay deposits. The backswamp muds were frequently dessicated.

(D) COARSENING-UPWARD GRAY SHALE TO SANDSTONE LITHOFACIES

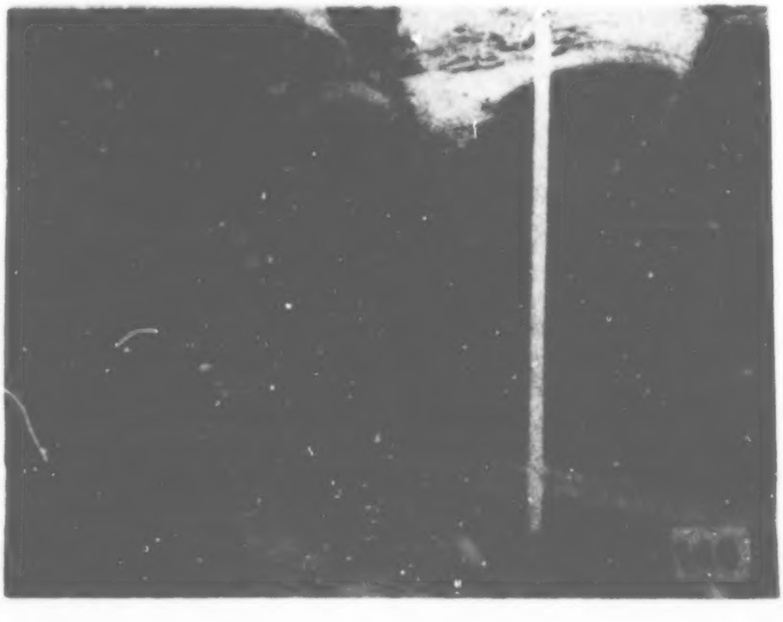
Description of lithofacies D: This lithofacies, which forms less than 1% of the Searston Formation type section, occurs at the top of some sandstone units of lithofacies A (Figure 40A). It consists of gray shales overlain gradationally by fine green-gray sandstones (Plate 139) resembling those of lithofacies A. The shales, which contain thin silt laminae and lenses, lie sharply upon the flat top of the underlying sandstone. The overlying sandstones exhibit planar stratification, or ripple-drift, overlain by small sets of crossbeds. The gradational base of one sandstone unit was partly eroded by a scour within the basal few centimetres of the same sandstone.

Sandstone dikes cut one of the gray shales (Plate 140). The dikes occur above convoluted sandstone in the underlying channel sandstone unit. The dikes pass up through the overlying cross-laminated sandstone, into an inverted, cone-shaped body of structureless sandstone. The cone, 20 cm in diameter at the top, is capped by a pan-shaped area, 200 by 100 cm in size and 12 cm thick, of structureless sandstone below a second shale layer.

Interpretation of lithofacies D: This lithofacies, lying sharply on top of lithofacies A sandstones and beneath thick floodplain sediments, is interpreted as deposits of abandoned chute or meander channels which were still open to the main channel. The lack of mudcracks in the shales indicates a shallow, quiet pool into which fine sand from the main channel was carried during floods to form a coarsening-upward sequence. Sedimentary structures in the sandstones suggest the rapid deposition of fine sand by currents that



Plates 139 to 140: Sandstones and gray shales of lithofacies D, Searston Formation near Kennedy Point. The shales are gradationally overlain by the sandstones which are laminated and cross-laminated. Note the deformation of internal structure in the underlying sandstones and the narrow sandstone dike cutting through the shales (Plate 140).



decelerated as they flowed into the open end of the pool. The convolution of structures in the sandstones beneath the shales and the presence of sandstone dikes cutting the shales suggest that the impermeable shales confined pore waters within the sands. The sands were liquified due to differential loading or shocks that occurred during river floods and destabilized them (Reineck and Singh, 1975, pages 78-79).

(E) COAL LITHOFACIES

Description of lithofacies E: The coal beds of the upper coal-bearing sequence in the St. George's coalfield are rarely thicker than 60 cm and are the least known facies of the group. Some coal seams are up to 115 cm thick; they consist of interlayered coal and shale (Bryan, 1938). Many of the coals lie directly on gray sandstones of lithofacies A or upon dark gray mudstones which in turn overlie the thick sandstones. Seams begin with the thickest coal layers at the bottom. Shale and some sandstone partings gradually increase in number upward and the seams are capped by 10 to 45 cm of shale or interlayered shales, mudstones, and sandy mudstones below the next major sandstone member. In some seams, Bryan (1938) noted discontinuous coal laminae and lenses in the upper shales.

Coals in the Codroy lowlands appear to be lenticular, with shale partings splitting seams (Hayes and Johnson, 1938). Channelling at the base of overlying sandstones cuts down through the coal seams.

The coals generally contain less than 10% ash, 1 to 4% sulfur and about 30% volatile matter (Bryan, 1938; Hayes and Johnson, 1938; Hayes, 1949).

Interpretation of lithofacies E: It appears that the coals were deposited in the flood plain adjacent to channel sandstones, either directly on the sandstones or upon an underclay. Ash, sulfur and volatile matter content is similar to that of floodplain coals of the Sydney coalfield (Hacquebard and Donaldson, 1969).

(F) BROWN CONGLOMERATE-SANDSTONE LITHOFACIES

Description of lithofacies F: This lithofacies, present only in the coastal section south of Trainvain Brook (Figure 39), unconformably overlies pre-Carboniferous crystalline basement (Plate 141). It is composed of three main lithologies; i.e. conglomerates, pebbly and sandy mudstones, and pebbly, muddy sandstones and siltstones. All lithologies are deep brown in color.

Plate 141: Unbedded conglomerates of lithofacies F, Searston Formation lying unconformably upon rotted basic rocks of the Long Range mafic and ultramafic complex, 1/2 km south of Trainvain Brook.

Plate 142: Close up of subrounded pebbles in the basal conglomerate at Trainvain Brook. Note matrix-supported and unsorted nature of deposit.

The conglomerates comprise the lower 40 m of the section, above which they are interlayered with sandstones. The conglomerates are mostly ungraded and consist of matrix-supported pebbles and cobbles (Plate 142), some as large as 73 cm on their long axis. The subrounded clasts are set in a gritty to muddy brown matrix with clasts rimmed by an iron oxide coating. Numerous small pores are present in the matrix. Cobble-size, conglomeratic intraclasts derived from erosion of a previously deposited conglomerate bed also occur; the intraclasts contain 2-3 cm diameter pebbles. Overlying the unconformity, bedding and grading in the conglomerate are absent for several metres. A vague fabric is discernible parallel to bedding and lenses of sandstone fill shallow depressions. These features suggest that the conglomerates are amalgamated. Above the unbedded sequence, conglomerates are ungraded and matrix-supported but are bedded on a scale of 1 to 2 m, and, in some places, at 4.5 m intervals (Plate 143). Planar stratified, medium to coarse grained sandstones up to 45 cm thick infill irregularities in the tops of the conglomerates.

Higher in the section, the conglomerates grade into muddy, pebbly, coarse and very coarse sandstones. The beds vary from 1.5 to 3 m thick. Erosive bases and some cobble-size clasts characterize the conglomerates. The sandstones are internally crudely stratified. The stratification is usually flat-lying or slightly inclined and, in some places, drapes over the hummocky tops of the conglomerate.

Structureless, pebbly mudstone in beds 87 to 250 cm thick is interbedded within the basal conglomerates. Pebbles 3 to 15 cm in size are scattered throughout the sandy mudstone matrix, which locally has a crude fissility.

Although they are only thin lenses in the basal 40 m of the section, the sandstones form beds and lenses 10 to

Plate 143: Thick crude bedding and lenses of pebbly sandstones in conglomerates of lithofacies F, Searston Formation, 15-20 m above unconformity, Trainvain Brook.

Plate 144: Thick conglomerate beds with lenses of brown, thin bedded sandstones (lithofacies F, Searston Formation) overlain by crossbedded, muddy, red sandstones. Searston Formation, south of Trainvain Brook.

160 cm thick in the upper 60 m where they are interbedded with the conglomerates (Plate 144). The lower sandstones are poorly sorted, lie on a scoured base, and are both graded and structureless. Higher in the section, however, they contain thin planar stratification and planar and trough crossbeds, some up to 60 cm thick (Plates 145 and 146). Hard, spherical, calcareous concretions are also common (Plate 146).

Crossbeds measured in the sandstones indicate a west-southwest direction of paleoflow.

Interpretation of lithofacies F: The conglomerates and muddy sandstones of this lithofacies are proximal deposits of an alluvial fan.

The ungraded, unbedded to bedded, matrix-supported, cobble to pebble conglomerates of the basal 40 m possess the characteristic features of debris flows (Hooke, 1967; Bull, 1972; Walker, 1975a). Structureless to crudely fissile pebbly mudstones interbedded with the debris flows are probably mudflow deposits (Sharp and Noble, 1953; Bull, 1972); the crude fissility was probably caused by shear within the flow after it had almost solidified, but may also be a product of compaction.

Pockets of sand between debris flows indicate reworking of tops of flows by shallow streams or sheetwash (Bull, 1972).

The transition upward in the section from basal conglomerates into sandstones and conglomerates is marked by coarse, lenticular and bedded, graded conglomerates and sandstones which were probably distal debris flow and channel-bound braided stream deposits. The latter include the crossbedded and planar stratified sandstones that are interbedded with pebble beds in the upper 60 m. The pebble beds were probably deposited as longitudinal gravel bars (Rust, 1972, 1978; Smith, 1974), and the planar and trough crossbeds formed as transverse bars (Smith, N.D., 1971, 1972) and in-channel megaripples (Harms, 1975; Miall, 1977) such as commonly occur in gravelly and sandy braided streams (Rust, 1972; Miall, 1977, 1978). Size of structures and high mud content suggest streams choked with fine sediment.

Paleocurrent directions and the composition of detritus suggest the fan built out westward from mountains southeast of the Long Range fault. The upward decrease of pebble size and the change in textural character from coarse debris flow deposits to braided stream gravel and sand deposits suggest that the section is part of an upward-fining megasequence (Heward, 1978a). This implies recession of the source area and prolonged tectonic stability at the basin margin (Bluck, 1967; Steel and Wilson, 1975) following uplift of the source area and initial formation of the fan.

Paleocurrents in the Barachois Group

Diagrams of paleocurrent directions collected from strata of the Searston Formation in the Codroy lowlands are shown in Figure 38. No data are available for the group in the St. George's coalfield. The diagrams present a broad asymmetrical paleocurrent spread which is strongly bimodal toward the southwest and the northeast. Such bimodal distributions are typical of meandering river channels (Allen, 1965a) and suggest that the rivers flowed toward the west and northwest.

Ripple cross-lamination from fine sandstones at the top of lithofacies A and from sandstones in the intervening siltstone members of lithofacies B and C indicate a polymodal distribution. This would be expected of deposits on levees or in small streams or crevasse-splays on the flood plain.

Plate 145: Brown, muddy sandstones displaying planar thin stratification with pebble layers, near top of Trainvain Brook section. Searston Formation.

Plate 146: Crossbeds and spherical concretions (to right of metre stick) in brown-red sandstones of top of Trainvain Brook section, Searston Formation.

Petrography of the Siliciclastics of the Barachois Group

The sandstones of the Barachois Group, of which 38 thin sections were examined, are compositionally arkoses and subarkoses. There are, however, some clear differences in mineralogy between sandstones of the Searston Formation in the Codroy lowlands and those of the undivided Barachois Group in the St. George's coalfield.

Channel sandstones (lithofacies A) are poorly to moderately sorted (Beard and Weyl, 1973), with variable amounts of clay matrix and calcite cement. Interlocking, sutured grain boundaries occur where matrix is absent and sandstones are better sorted. Quartz grains, which commonly have quartz overgrowths, typically have low to moderate roundness. Feldspars are generally prismatic and heavy minerals are characteristically irregular fragments or are prismatic in shape. Calcite cements are most common in the coarsest sandstones at the base of the fining-upward sequences or in planar crossbedded, coarse, pebbly sandstones near the top of channel sandstone members. The calcite cements partly or completely replace the matrix, etch and fill fractures in quartz grains, and also extensively affect the micas and feldspars, including the feldspar crystals within granitic rock fragments. The mica plates were forced apart as cement precipitated along cleavage planes.

Sandstones and siltstones of lithofacies B and C contain more micas, heavy minerals and matrix. Commonly, these are cemented by carbonate which locally forms small spherical patches resembling incipient caliche nodules.

Searston Formation, Codroy lowlands

Severely strained and undulose quartz grains, several types of composite quartz, feldspars, one or more phyllosilicates, a variety of lithic fragments and heavy minerals comprise the arkoses of the Searston Formation type section.

The strained quartz grains contain numerous microfractures, vacuoles, criss-crossing vacuole trains, and common deformation lamellae and exhibit pronounced undulose extinction. Flaser quartz was also observed locally. Both single quartz grains and "common" composite quartz (Folk, 1968) contain vacuoles and micro-inclusions such as rutile needles, apatite, micas, zircon and tourmaline. Vein quartz, rarely with comb structure and chalcedonic layering, and metamorphic quartz that includes granoblastic, stretched and schistose types also occur. Elongate fragments of silicic mylonite were also noted.

The main feldspars are fresh to altered orthoclase and plagioclase. Sericitization and vacuolization are the most common indicators of alteration. However, kaolinization of the feldspars was noted in some thin sections and possibly contributed to *in situ*, postdepositional formation of a clay matrix. Microclines and perthites are common in the channel sandstones near Northwest Cove and Larkin Point. They are the main feldspars in the basal 60 m of the section at Kennedy Point. In the overlying 150 m of sandstones and siltstones, however, microclines and perthites are rare. Perthites include stringlet, rod, bead and patchy replacement types (Alling, 1938). They are variably altered whereas microclines are mostly fresh.

Muscovite and green biotite are the most common micas but chlorite plates and felted grains and some brown biotite also occur. Micas are most common in the sandstones of floodplain red and gray beds.

Plutonic rock fragments include tonalites and granites composed of quartz-perthite, quartz-microcline or quartz-K feldspar-plagioclase + muscovite, and plagioclase + quartz.

Generally elongate quartz-muscovite or sericite schists, phyllites and chlorite schists are typical metamorphic rock fragments. Rare devitrified, spherulitic and cherty silicic volcanic grains and some rarer mafic volcanic grains containing plagioclase microlites in a chloritized matrix also occur.

Heavy minerals are unevenly distributed but are most abundant in floodplain sandstones. They consist of abundant magnetite, zircon, and green, yellow, blue and rarely pink tourmaline. Garnets, some with abundant inclusions and others affected by chloritic alteration, sphene, leucoxene, rutile, epidote, clinozoisite, and rare cassiterite, monazite and staurolite complete the detrital suite.

Marginal deposits, Trainvain Brook

Highly strained quartz and metamorphic quartz, fresh to altered plagioclase, plagioclase-rich plutonic rock fragments, phyllites, quartz-muscovite ± zoisite schists, some serpentine grains, and muscovite, green biotite and some chlorite comprise lithofacies F sandstones at Trainvain Brook. Heavy minerals include abundant zoisite and epidote, as well as some magnetite, green hornblende and actinolite-tremolite. Matrix is abundant but is heavily impregnated by brown amorphous iron oxides.

Sandstones, St. George's Bay lowlands

The detrital components in channel sandstones of the Barachois Group in the St. George's coalfield differ from those in the Searston Formation by the absence of highly strained quartz, the abundance of microcline and perthitic feldspars, and the scarcity of micas and heavy minerals.

Quartz has normal to undulose extinction and rare fractures and strain lamellae. Embayments and clearness of many quartz grains suggest a volcanic source. Composite "common" quartz, vein, and plutonic composite quartz and some metamorphic quartz also occur. The feldspars, including microcline, perthite, orthoclase and some plagioclase, can be fresh but most show minor to advanced sericitization and cloudiness caused by vacuolization. Granitic rock fragments also contain altered and unaltered feldspars which may be zoned with cloudy centres and unaltered rims. Spherulitic, devitrified, cherty and porphyritic silicic volcanic grains and some microlitic basic volcanic grains are common. Quartz-muscovite or sericite schists and phyllites, plus some fragments of argillaceous siltstone make up the rest of the rock fragments. Muscovite and some chlorite are the main phyllosilicates but are not abundant. Zircon, tourmaline, some garnet and rare sphene or rutile are accessory detrital minerals.

Paleontology, Age and Correlative Deposits of the Barachois Group

Miospores and macroflora, principally from the Searston Formation, are listed in Table 11. Miospores from the Searston Formation were recovered from older beds at Kennedy Point and the youngest strata of the formation at Northwest Cove. The miospores were identified by Utting (personal communication, 1978). Both localities contained assemblages that included *Schulzospora* sp., *Grandispora spinosa*, *Potonieisporites elegans* and *Knoxisporites triradiatus*; these were also recently documented in assemblage III of the Windsor Group (Utting, 1980). They were also noted in beds of the upper part of the Hastings and lower Pomquet Formations of Antigonish and southwestern Mabou, Nova Scotia (Neves and Belt, 1970).

Several plant fragments were also noted by Bell (1948) from the Searston Formation; Bell also recorded the presence of ostracods, fish scales and coprolites from an oil shale in probable Searston Formation strata along Crabbes Brook.

TABLE 11: Fossil flora from Searston Formation and upper coal-bearing sequence, Barachois Group. Kennedy Point at base of and Northwest Cove near top of Searston Type section. Spores from Coal and Stevensons Brooks, Codroy lowlands, retrieved from coal beds. Identification by Utting (pers. comm., 1978, M.Sc. thesis, 1966). Limited macrofloral elements for the two divisions of the Barachois Group are also listed (from Hayes and Johnson, 1938; Hayes, 1949; Bell, 1948; Utting, 1966).

MICROFLORA

Kennedy Point		**Northwest Cove**		**Coal Brook and Stevensons Brook**
Sample 75-3-3	**Sample 75-7-4**	**Sample 77-C3-6**	**Sample 77-C3-7**	
Knoxisporites stephanephorus	*Retusotriletes incohatus*	*Dictyotriletes* cf. *D. sagenoformis*	*Granulatisporites granulatus*	*Calamospora* sp.
Discernisporites sp.	*Kraeuselisporites* sp.	*Punctatisporites irrasus*	*Calamospora* sp.	*Cirratriradites* sp.
Rugospora polyptycha	*Knoxisporites triradiatus*	*Punctatisporites planus*	*Punctatisporites* sp.	*Denosporites* sp.
Retusotriletes incohatus	*Lycospora noctuina* var. *noctuina*	*Apiculatisporis* sp.	*Lophotriletes* sp.	*Knoxisporites* sp.
Schulzospora sp.	*Auroraspora macra*	*Lophotriletes* sp.	*Lycospora noctuina* var. *noctuina*	*Leiotriletes* sp.
Schopfipollenites sp.	*Schopfites claviger*	*Leiotriletes* sp.	*Schopfipollenites* sp.	*Lophotriletes* sp.
Lycospora noctuina var. *noctuina*	*Granulatisporites granulatus*	*Granulatisporites granulatus* and *Schopfipollenites* sp.	*Knoxisporites triradiatus*	*Lycospora* sp.
Apiculatisporis sp.	*Raistrickia* sp.		*K. stephanephorus*	*Punctatisporites* sp.
Potonieisporites elegans	*Schulzospora* sp.		*Perotriletes perinatus*	*Raistrickia* sp.
	Dictyotriletes sp. and fragment only of *Potonieisporites elegans* (?)		*Rugospora* sp.	*Savitrisporites nux*
			Calamospora perrugosa	*Schopfipollenites* sp.
			Endosporites minutus	*Waltzispora* sp.
			E. micromanifestus	
			Discernisporites sp.	
			Secarisporites remotus	
			Reticulatisporites cf. *R. polygonalis*	
			Dictyotriletes sp.	
			Planisporites sp.	
			?Lophozonotriletes sp.	
			Retusotriletes incohatus	
			Apiculatisporis baccatus	
			Leiotriletes sp.	
			Auroraspora balteola	
			Grandispora spinosa	

MACROFLORA

Searston Formation	**Upper Coal-bearing sequence from St. George's Coalfield**
Lepidodendron volkmannianum	*Sphenopteris hoeninghausi* Brongniart
Diplotmema adiantoides	*Calamites* sp.
	Stigmaria ficoides (Sternberg)
	Lepidodendron sp.

The mioflora of the formation thus suggest that the formation lies near the Visean-Namurian boundary. Utting (personal communication, 1978), prior to defining assemblage III of the Windsor Group (Utting, 1980), suggested that the spores were younger than assemblage II of the Windsor Group and probably comparable to spores of the upper Hastings Formation. This is supported by several spores; in particular, by the presence of rare *Potonieisporites elegans* and *Grandispora spinosa*, which indicate an early Namurian age. Macroflora also indicate an earliest Namurian age (Bell, 1948). The Searston Formation is thus equivalent to Cansoan strata of Nova Scotia (Belt, 1968a) that include both lacustrine and fluvial strata of the upper Hastings and lower Pomquet Formations (Belt, 1965; Neves and Belt, 1970).

The age of the upper coal-bearing sequence ranges from Westphalian A to C. Coal beds of the Codroy lowlands and the St. George's coalfield are dated as Westphalian A (Hacquebard et al., 1961), but the coal measures of the Codroy lowlands are apparently slightly older than those of the St. George's coalfield (Utting, 1966). Both correlate with Riversdalian strata of Nova Scotia (Belt, 1968a; Hacquebard et al., 1961; Hacquebard, 1972). Coal beds on Blanche Brook near Stephenville yield a flora of Westphalian C age (Riley, 1962) and, hence, are equivalent to strata of the Pictou Group of Nova Scotia (Riley, 1962; Belt, 1969).

Depositional Environment of the Barachois Group

Repetitive fining-upward fluvial sequences of green-gray sandstones and red, red and gray, or gray to black fine beds that typify the Barachois Group are interpreted as deposits of meandering river channels and adjacent floodplain and backswamp environments. Petrographic and paleocurrent data suggest the rivers flowed northwestward across the flood plain away from a mountain range that lay southeast of the Long Range fault. Subsidence and sedimentation continued steadily throughout the history of the group but the climate became increasingly humid. The mountain-subbasin contact probably lay southeast of the Long Range fault, the fluvial floodplain deposits passing into fanglomerates near the mountain front.

The sedimentological characteristics of the sandstones of the Searston Formation resemble those attributed to deposition in meandering river channels (Allen, 1964a, 1965a, 1965b; Walker, 1979a). The coarse grain size and the preservation of crossbedded deposits interpreted as scroll or chute bars within some sandstones suggest many deposits closely compare to those of modern, low sinuosity, bedload-dominated rivers (McGowen and Garner, 1970; Jackson, 1975, 1976). Levees flanked the channels and meander cutoffs were commonly plugged by dark shales following channel abandonment; in some places, channels were later reoccupied.

Multistory channel sandstones support the presence at times of stabilized meander belts. In general, however, the abundance of single-story fining-upward sandstone sequences, abrupt upward transition in some units from point bar sandstones to overbank sediments, and the lack of mature caliches in floodplain deposits suggest that the meandering rivers ranged freely over the flood plains. Channel direction probably changed as avulsion of channels occurred randomly on the flood plain or near the point at which the river system discharged from the mountain range into the subbasin (Leeder, 1978; Allen, 1965a). Preservation of well-developed floodplain deposits suggests that steady subsidence of the subbasin occurred and probably encouraged switching of channel direction.

Similar channel types probably occurred in the Barachois Group in the northern part of the subbasin. However, information is still inadequate to confirm this interpretation and the importance of pebbly sandstones in the succession may indicate that deposition also occurred from low sinuosity streams.

Sedimentation beyond the channels occurred when crevassing, channel breaching, or flooding occurred and fine sediment was swept onto the flood plain. Crevasse-splays deposited laminated and current-rippled sand and silt near the channels. Finer grained, well to poorly bedded sediments were deposited further away from the channels on the flood plain.

Red, oxidized, vertical-accretion deposits characterize the lower 1600 m of the Searston Formation and contain plant rootlets, mudcracked surfaces and caliche nodules indicative of soil horizons. Only locally did depressions in the flood plain produce drab colored deposits. Small streams locally reworked the oxidized floodplain deposits. Above the 1600 m level, however, green-gray silty mudstones and shales containing thin sandstone beds and abundant plant detritus are intercalated with the fine redbeds. These sedimentary rocks suggest that the floodplain environment changed so that poorly drained swamps developed near the channels. Ponds, lakes and broad muddy swamps periodically blanketed by sheets of crevasse-splay sands and silts are characteristic of the swamp environment. Early cementation occurred in the sheet sandstones, possibly similar to early paludal cements described by Freytot (1973). Proliferation of vegetation with time eventually led to the formation of narrow and extensive peats that formed the lensoid and bedded coals of the upper coal-bearing sequence. Their development suggests stabilized channel belts (see Hacquebard and Donaldson, 1969).

Only one glimpse of the margin of the subbasin is preserved at Trainvain Brook in the extreme southeastern part of the subbasin. There, a highly oxidized fanglomerate sequence composed of debris flow conglomerates overlain by stream-lain conglomerates and sandstones was deposited unconformably upon older Paleozoic metagabbros of the Long Range mafic-ultramafic complex (Brown, 1977). The fanglomerate deposits lie southeast of the Long Range fault, suggesting the mountain-subbasin boundary did not coincide with the fault (as already postulated for the upper beds of the Codroy Group) but was some distance to the southeast. This is supported by the lack of basin-margin facies at Coal Brook, where the upper coal-bearing sequence abuts the Long Range fault.

Red, oxidized floodplain deposits with nodular caliche in the lower 1600 m of the Searston Formation indicate semiarid climatic conditions during the early history of the group (Walker, T.R., 1967a; van Houton, 1973; Gile et al., 1966; Allen, 1974; Leeder, 1975). The presence of only nodular caliche indicates, however, that advanced soil-forming processes were inhibited, probably by a high sedimentation rate in the flood plain (Leeder, 1975). This, supported by the generally coarse sand to pebbly sand transported by the rivers and the relatively large size of river channels and meander belts calculated from bankfull thickness of sandstone members (Leeder, 1973; Collinson, 1978b), indicates high precipitation, at least in the source mountains, and frequent flooding of river basins. The importance of drab beds, the abundance of plant remains, and the presence of coal beds toward the top of the group suggest increased humidity in both the basin and adjacent mountain belts by the early Namurian. This more humid climate lasted until Westphalian times, when the main coals preserved in the subbasin were deposited.

Paleocurrent and petrographic studies of the sandstones of the Barachois Group in the Codroy lowlands and the St. George's coalfield support the derivation of the sediment from mountain ranges southeast of the Long

Range fault. Detritus in the two basinal sequences compares favorably to that expected from rock types southeast of each sequence across the fault and argues against any significant lateral displacement along the Long Range fault since deposition of these rocks. Strained quartz grains, different feldspars, in particular perthites, microcline and abundant plagioclase, rock fragments, especially tonalite and granite, metasediments and mylonitic quartz characterize the basal sandstones of the Searston Formation in the Codroy area. This detrital assemblage supports derivation from a deformed basement terrane that was composed mostly of tonalites and granites and was cut by major shear zones. Such a terrane presently underlies the Long Range Mountains southeast of the Codroy lowlands (Chorlton and Dingwell, 1981; Chorlton, personal communication, 1981). Some felsic volcanic and low grade metasedimentary rocks also lay in the source area. Pebble types and the prevalence of zoisite and epidote in the Trainvain fanglomerate southeast of the fault support local derivation from metagabbros and granitic and tonalitic rocks of the southwestern corner of the Long Range Mountains.

The detritus in the sandstones of the St. George's coalfield, in particular the abundant cloudy feldspar and granitic and silicic volcanic rock fragments, compares to that of the Brow Pond lentil (Codroy Group). These clasts were clearly derived from a suite of mostly undeformed granites and felsic volcanics with some low grade metasediments. This suggests a source similar to the Siluro-Devonian Topsails Igneous Complex (Taylor et al., 1980) or Lloyd's River intrusive suite (Kean, in preparation), which now lie to the northeast of the subbasin but probably extended southwestward close to its edge. Hyde and Ware (1980, 1981), studying time-equivalent coal-bearing strata of the Howley Formation of the Deer Lake Basin, also concluded that detritus in sandstones of the formation was derived from the Topsails Igneous Complex immediately southeast of the Deer Lake Basin. This petrographic evidence must preclude significant post-depositional lateral displacement of geologic terranes across the collinear, related faults that form the south-eastern margins of both the Deer Lake Basin and the Bay St. George subbasin.

The thickness of the succession, the generally consistent grain size of sandstones throughout the succession and repetitive fining-upward sequences support steady subsidence of the subbasin. Nearly 2600 m of strata was deposited in the Searston Formation in about 4 million years during the early Namurian. This gives an average rate of sedimentation of about 6 m per 1000 years. The presence of Pictouan-age sediments near Stephenville suggests the humid, fluvial, coal-bearing sedimentation described here for the younger rocks of the group continued for at least 25 million years until the end of the Westphalian Stage of the Pennsylvanian.

CHAPTER 3

STRUCTURE AND METAMORPHISM

Part I - Structure

Introduction

Carboniferous strata of the Bay St. George subbasin are deformed principally by northeasterly trending folds and faults produced during the Hercynian Orogeny in post- or Late Pennsylvanian times. The major structures trend parallel or subparallel to the Long Range fault (Figure 42), which bounds the basin on its southeastern side. They are interpreted to have formed in response to strike-slip movements along the Long Range fault and faults within the subbasin; the type and geometry of the structures conform closely to the model of wrench fault systems outlined by Wilcox et al. (1973). Vertical displacements also occurred along the Long Range and other faults. Folds vary from open and upright to tight and overturned. They are cut by a conjugate set of northeasterly and northwesterly trending faults formed in response to the wrench movements. Later faults with easterly trends have locally juxtaposed inverted rock sequences against upright sequences of the same unit, e.g. the Woody Cape Formation.

Structural style is generally simple in the north where Precambrian basement gneisses underlie Carboniferous strata at shallow depth (Riley, 1962; Geological Survey of Canada, 1968; Belt, 1969). In the south, particularly beneath the southern Anguille Mountains, the structure is quite complex, and reflects the great thickness of the succession and the relative competence of the lithologies. Here, the basement is probably located at least 6 km below the present surface (Hobson and Overton, 1973).

Several kinds of structures are present; namely, (1) northeasterly trending folds, (2) thrust faults and décollement zones, (3) northeasterly trending faults, (4) northwesterly trending faults, and (5) easterly trending faults.

Northeasterly Trending Folds

Several large northeasterly trending folds have deformed the strata of the subbasin. The major folds named on the map are: (1) the Anguille anticline, part of a major anticlinorium exposing Anguille Group strata in the Anguille Mountains; (2) the Flat Bay anticline, which exposes basement beneath strata of the Anguille and Codroy Groups near Flat Bay; (3) the Barachois synclinorium, which folds rocks of the Barachois Group in the St. George's Bay lowlands.

The St. David's syncline, which occurs in rocks of the Robinsons River Formation, plunges and trends northwestward against the main tectonic grain of the subbasin but is nevertheless described herein.

Anguille anticlinorium and folds beneath Bald Mountain

The broad outcrop pattern in the Anguille Mountain area reveals the presence of a large doubly plunging anticlinorium (pericline) that is modified by numerous subsidiary folds and is cut by the Snakes Bight fault close to its axial plane. The Snakes Bight fault separates folded strata of the Anguille Group to the southeast from a northwesterly younging sequence of Anguille Group strata northwest of the fault along St. George's Bay. This sequence probably represents the faulted northwestern limb of the original anticlinorium. The northwest limb strikes approximately northeasterly and varies from moderately dipping to overturned. From Highlands River southwest to Pauls Gulch, it strikes east-northeast and dips from 40-60° to the northwest. Southwestward toward Friars Cove and Cape John, the strike changes to northeasterly and the dips steepen to vertical and then become overturned, dipping about 50° to the southeast.

Southeast of the Snakes Bight fault, the Anguille Group is folded into a series of open, upright to slightly overturned, northeasterly trending folds. The folds are arranged in an *en echelon* pattern and abut the Snakes Bight fault at an angle of 30° to 35°.

In the centre and southwest of the Anguille Mountains, the stratigraphically lowest Kennels Brook Formation occupies the core of the Anguille anticlinorium. The structure is essentially an open, upright, slightly asymmetrical, doubly plunging structure. Cleavage is locally developed in the formation and in the overlying Snakes Bight Formation. It strikes parallel to the 033° trend of the fold axis and dips mostly southeast 35° to 62° on both limbs, although locally it is subvertical near the hinge of the fold. Bedding plane slip, shown by slickensides generally oriented perpendicular to cleavage and bedding trends, is common throughout the southwestern part of the mountains. Second-order folds deforming the Kennels Brook Formation occur on the northwest limb of the Anguille anticline near Hynes Gulch. Several first- and second-order folds that trend parallel to the Anguille anticline and plunge between 6° and 14° to the southwest are developed in rocks of the Snakes Bight Formation at the southwest end of the Anguille Mountains. Second-order folds, many of which are tight structures, are concentrated in the Snakes Bight Formation around the main hinge zone of the Anguille anticline as it is traced to the southwest near Brooms Brook. The Low Brook syncline, a first-order fold, lies between the Anguille anticline and the Snakes Bight fault. Parasitic folds occur in the core and on the limbs of this syncline.

The Brooms Brook syncline and Brooms Hill anticline are tight folds overturned to the northwest, with axial surfaces dipping about 55° southeast (cross-section D, Figure 43). Local reverse faults, with traces parallel to the fold axes, occur on the inverted limb. Other folds on the southeastern limb of the anticlinorium further to the southeast are open, upright structures, the axes of which are truncated to the south by the northeasterly trending Ryans Brook fault. The traces of these fold axes consistently intersect the Snakes Bight, Ryans Brook and Long Range faults at angles of 18° to 25°.

To the northeast in the Anguille Mountains, the Anguille anticlinorium changes gradually to a large, open, anticlinal structure with only a few secondary folds. The major anticline and the parasitic folds here plunge 4° to 11° northeast and the trend of the major structure and the Snakes Bight fault swings to 068°. The last-named fault lies along or near the hinge zone of the anticline (cross-sections G to I, Figure 43). Minor folds southeast of the fault intersect it at an angle of 27°. The axial traces of these folds, however, can be followed only for short distances and are defined only close to the fault. Northwest of the Snakes Bight fault, an anticlinal axis which trends parallel to the fault can be traced for 11 km from Pauls Gulch to French Brook.

Open folding is present beneath Bald Mountain, where a number of upright folds trend 043° to 057°, nearly parallel to the Long Range fault.

Flat Bay anticline

This structure is a doubly plunging, open, periclinal fold trending about 037°. Harmonic folding of both the Anguille and Codroy Group strata occurs around a core of Grenvillian crystalline basement. Dips on the limbs of the anticline gradually steepen to 50° away from the axis and locally reach 80° on the western limb.

Barachois synclinorium

The Barachois synclinorium occupies the St. George's coalfield (Hayes, 1949). It was originally called the St.

George's syncline by Riley (1962) but is renamed here because of newly acquired geometrical data. Its detailed structure is poorly understood because of insufficient exposure. Generally speaking, however, the structure from Northern Feeder to Crabbes Brook is dominated by a doubly plunging, broad, open syncline that trends 027°. North of Northern Feeder, a train of possibly related folds plunge 11° to 24° north-northeastward and trend approximately 030°. The folds are transected by the Crabbes Brook fault (Riley, 1962) and intersect it at an angle of 27°-30°. Dips in the synclinorium are moderate, steepening locally near faults, especially the Crabbes Brook fault.

St. David's syncline

The axis of St. David's syncline trends northwesterly and forms a plunge depression between the mouth of the Highlands River and St. David's. Both limbs dip 40° to 50° and the fold axis plunges at 30° to 39°. The fold is peculiar in the subbasin because of its conspicuous trend at right angles to the rest of the regional structures. No evidence of a second phase of folding is present in the subbasin. This probably suggests that the fold configuration results from its geographic position between the Anguille and Flat Bay anticlines and not because of compression. The fold may have been accentuated by movements on the Shoal Point fault to the south. The relatively steep plunge might have been produced by movements on a northeasterly trending fault that is believed to occur offshore in St. George's Bay. Salt movements at depth causing partial collapse may have been an additional factor in its formation.

Thrust Faults and Décollement Zones

Thrust faults and décollement zones developed locally in two sequences of relatively incompetent strata, i.e., the Snakes Bight and Codroy Road Formations.

Thrust faults of local extent and probably minor displacement occur in the Snakes Bight Formation near Snakes Bight. The thrusts form mostly where there is a competency contrast, such as where thick sandstone units overlie thick black shale units. For example, a thrust is developed in places at the base of the Snakes Bight Formation where black shales and thin sandstones overlie indurated sandstones of the underlying Kennels Brook Formation.

Slickensiding, polished fragments, small fractures and 20 to 50 cm thick calcite veins commonly occur in the thrust zones. Undeformed or drag folded strata are common above the thrust surfaces. Local bedding discordances across the thrusts are as much as 18°; other contacts are sharp and concordant. The thrust at the base of the Snakes Bight Formation has similar characteristics and is locally imbricated on a minor scale.

The thrust surfaces generally strike north-northeasterly to easterly and dip between 15° to 25° to the southeast. Displacements are probably restricted to a few tens of metres, the direction of translation being toward the west and northwest. Locally the thrusts are gently folded suggesting that they formed early in the deformation.

A décollement zone is developed at the base of the Codroy Road Formation in the central and northern areas of the Anguille Mountains, where fine siliciclastics and evaporites of the formation overlie the Ship Cove Formation. The decollement zone is marked by a zone of shattered and sheared rocks. Its presence is also supported by records of drilling (McKillop, 1953a; Smith, 1953) carried out in the Codroy Road Formation near Highlands River, northeast of Codroy Pond. The records indicate that a highly fractured and sheared zone of sediments and evaporites up to 6 m thick occurs immediately above the Ship Cove Formation. In addition, a major northeasterly trending lineament locally coincides with the outcrop trace of the top of the Ship Cove Formation. This lineament marks the probable location of the décollement from Highlands River 12 km northeast to Barachois Brook. Where bedding can be defined above the zone, it may locally dip in a direction opposite to that of the underlying beds. Nevertheless, the décollement zone follows the structural contours of the immediately underlying Ship Cove Formation and is traceable around the northern closure of the Anguille anticlinorium. This could be interpreted to mean that décollement predated folding. However, it is considered more likely that the incompetent Codroy Road Formation was mechanically disintegrated during upright harmonic folding as it slid by the more competent layers of the Ship Cove Formation.

Other Faults

High angle faults are common throughout the subbasin and trend parallel and perpendicular to the regional structural grain. They trend (1) northeasterly, (2) northwesterly and (3) easterly. Although all three orientations are obvious on the accompanying map, the major faults trend northeasterly.

Northeasterly trending faults

The major faults in the subbasin include the Long Range, Snakes Bight, Ryans Brook, Ryans Hill and Crabbes Brook faults (Figure 42). Major faults with similar trends are believed to lie offshore beneath St. George's Bay (see Belt, 1969; Webb, 1969; Spector, 1969; Golden Eagle Developments, 1975). The faults generally dip at high angles, between 60° and 90°, and have both vertical and lateral displacements. Right-lateral strike-slip motion is suggested by the *en echelon* fold trends associated with several faults; lateral displacements of rock units are, however, not obvious. Horizontal, vertical and moderately dipping slickensides occur on minor northeasterly faults. Small reverse faults have developed in tight overturned folds within the Anguille Mountains, an example being the fault associated with the Brooms Brook syncline and Brooms Hills anticline (section D, Figure 43).

Long Range fault

The Long Range fault extends as a generally straight structure along the full extent of the southeastern margin of the subbasin. It is only rarely exposed but is delineated by a prominent scarp or lineament on maps and airphotos. It is well defined by a sharp change in magnetic expression from the Long Range Mountains into the subbasin. The fault may bifurcate near South Branch, where an aeromagnetic high 15 to 20 km long and 2 to 3 km wide (Geological Survey of Canada, 1971) lies within the subbasin between South Branch and north of Coal Brook. This feature suggests an upfaulted wedge of basement or buried volcanic rocks in this area.

To the northeast, the fault continues into a belt of crystalline rocks where it forms a shear zone on Flat Bay Brook 180 m wide. Both subhorizontal and vertical lineations occur, leading Riley (1962) to suggest a complex fault history with last recorded movements as oblique-slip on a steeply dipping fault plane. In the Codroy area, the fault is exposed twice on the South Branch River and poorly on Stephens Brook. Elsewhere, along other streams in the Codroy lowlands, the contact is obscured by a narrow area of cover. No known exposures of the fault zone occur in the northern part of the subbasin. Studies of the pre-Carboniferous crystalline rocks in the southwestern Long Range Mountains show that the Long Range fault is there defined by a zone of cataclasis 800 to 1000 m wide (Phair, 1949; Chorlton and Dingwell, 1981). A narrow zone of cataclasis varying from 2 to 30 m wide, for the most part less than 20 m wide, occurs in the Carboniferous rocks. The zone is

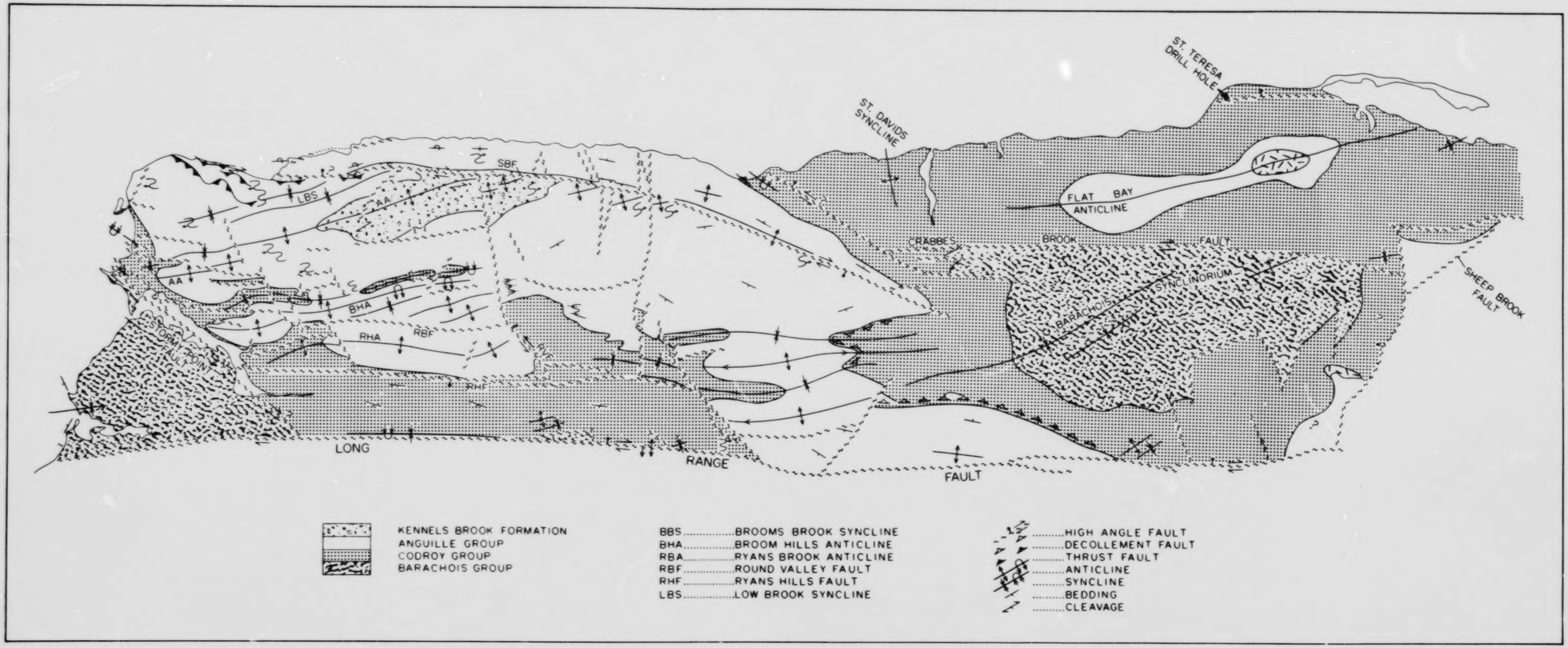

ST. TERESA DRILL HOLE
ST. DAVIDS SYNCLINE
SBF
LBS
AA
AA
BHA
RHA
RBF
RVF
RHF
STORMY POINT FAULT
FLAT BAY ANTICLINE
CRABBES BROOK FAULT
BARACHOIS SYNCLINORIUM
SHEEP BROOK FAULT
LONG RANGE FAULT
KENNELS BROOK FORMATION
ANGUILLE GROUP
CODROY GROUP
BARACHOIS GROUP
BBS.................BROOMS BROOK SYNCLINE
BHA.................BROOM HILLS ANTICLINE
RBA.................RYANS BROOK ANTICLINE
RBF.................ROUND VALLEY FAULT
RHF.................RYANS HILLS FAULT
LBS.................LOW BROOK SYNCLINE
..........HIGH ANGLE FAULT
..........DECOLLEMENT FAULT
..........THRUST FAULT
..........ANTICLINE
..........SYNCLINE
..........BEDDING
..........CLEAVAGE

Figure 42: Structural map of the Bay St. George subbasin showing main faults and fold axes and distribution of the main rock groups.

composed of deeply weathered, crushed sediment and lesser amounts of basement rock set in a rock flour. No slickensides were observed but quartz veins and minor fractures in the basement rocks contained a vertical lineation. Phair (1949), however, reported slickensiding plunging 42° to the northeast in the fault zone at Stephens Brook (Stevensons Brook in Phair, 1949). Chlorite is well developed on polished surfaces, particularly in the basement portion of the fault zone and in many small fractures and faults occurring in both sedimentary and crystalline rocks.

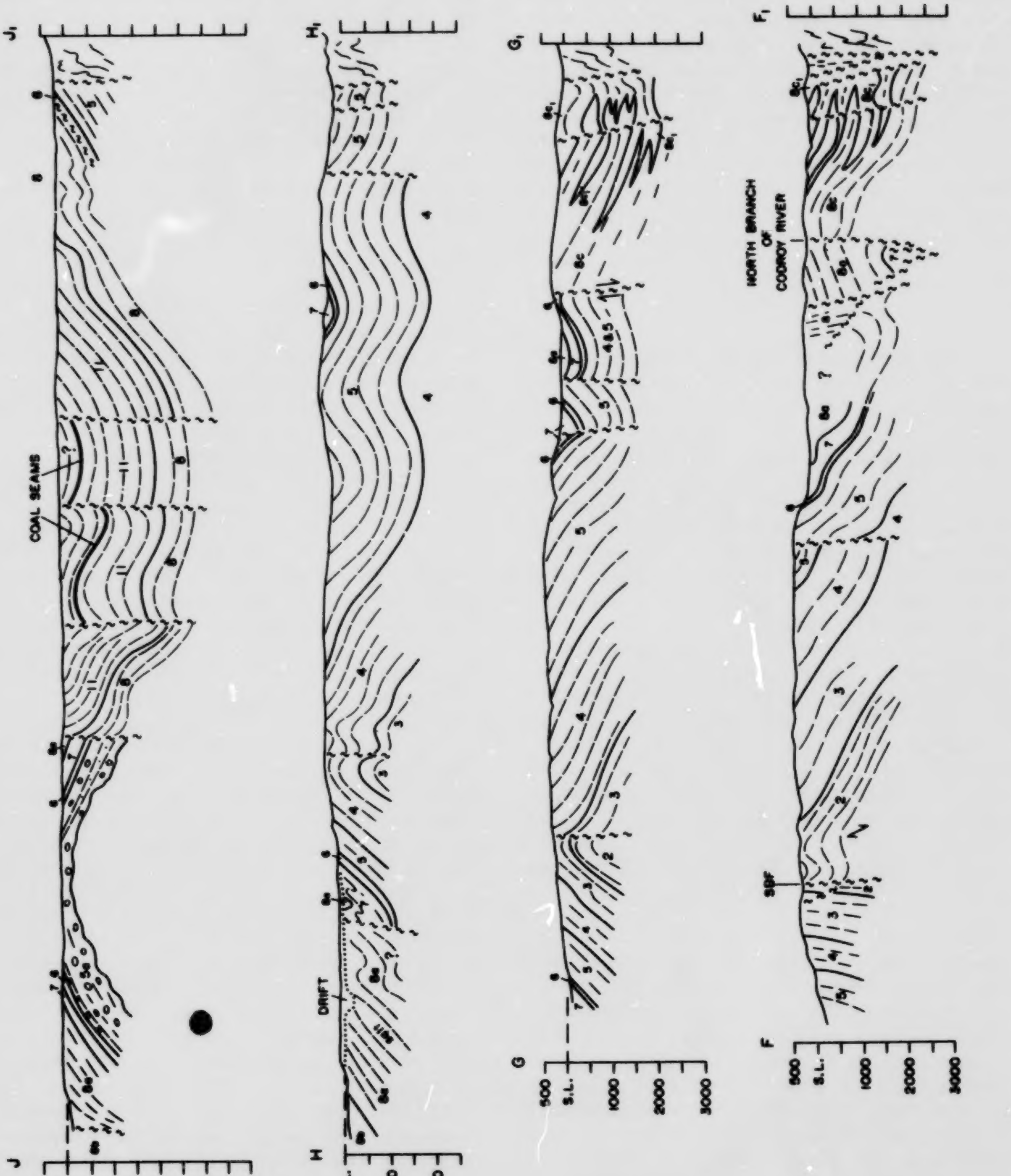
The fault plane strikes between 035° to 052° and dips 62 to 72° southeastward on Stephens Brook and at one of the South Branch River exposures. It is vertical in the other exposure on the South Branch River. At Johns Brook, the fault is not exposed, but minor parallel faults in the basement rocks adjacent to the zone dip basinward at 55° to 61°, suggesting that the main fault may also dip northwestward at that location. Phair (1949) reported that the fault dipped steeply basinward at 82° northwest at Stephens Brook but present work shows that it dips about 70° southeast. A southeastward dip is also illustrated by Hayes and Johnson (1938, Figure 16) for the fault contact. The dip of the fault at Coal Brook was estimated from drill logs as vertical (Phair, 1949), 80° to the southeast (Hayes and Field, 1948) and 70° to the southeast (Hayes, 1949).

Bedding adjacent to the fault surface mostly dips steeply away from the structure. Locally, it is overturned or folded into an open, overturned syncline parallel to the fault, for instance, the syncline folding the Overfall Brook Member. Vertical movement on the Long Range fault to accommodate the Carboniferous sedimentary pile must have been at least 10 km. No signficant lateral movement can be demonstrated on the fault, although Belt et al. (1969) and Webb (1969) suggested at least 100 km of dextral slip. These estimates, however, were based upon correlation of two mafic rock bodies on opposite sides of the fault which are now thought to be of different ages and compositions. The mafic rocks in the southern Long Range Mountains are now interpreted as Lower Ordovician ophiolitic rocks (Brown, 1977), whereas, the rocks of the Steel Mountain and Indian Head complex are anorthosites and gneisses of Grenvillian age (Lowden et al., 1963).

Snakes Bight fault

The Snakes Bight fault transects the Anguille anticline and is represented by a prominent northwestward facing fault scarp and, locally, an airphoto lineament. The fault outcrops at the coast in Snakes Bight and in a stream between Hynes Gulch and Wreck Cove. It dips between 75° and 90° southeastward and is represented by a 2 to 4 m wide zone of crushing and brecciation. A fault breccia of angular to rounded sandstone fragments set in a chloritic sand-shale rock flour matrix occurs in the stream exposure. The fragments resemble augen and are flattened by a cleavage which strikes 071° and dips 69° southeast.

The Snakes Bight fault trends virtually parallel to the Long Range fault in the southwest but farther northeast it swings eastward. There the angle of intersection between the Snakes Bight and Long Range faults is about 25°. The outcrop pattern indicates that there is little apparent displacement at the northeastern end of the Snakes Bight fault; the amount of apparent displacement increases southwestward. Such an outcrop pattern may reflect movements involving either downthrow to the northwest followed by right-lateral strike-slip, or oblique-slip to the northeast in response to dextral shear. However, the large amount of displacement in the southwest might also imply that the Snakes Bight fault is a scissors fault which hinged in the extreme northeast, with downthrow to the northwest.


J₁
J
COAL SEAMS
500
S.L.
1000
2000
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4000
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H
DRIFT
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G₁
G
500
S.L.
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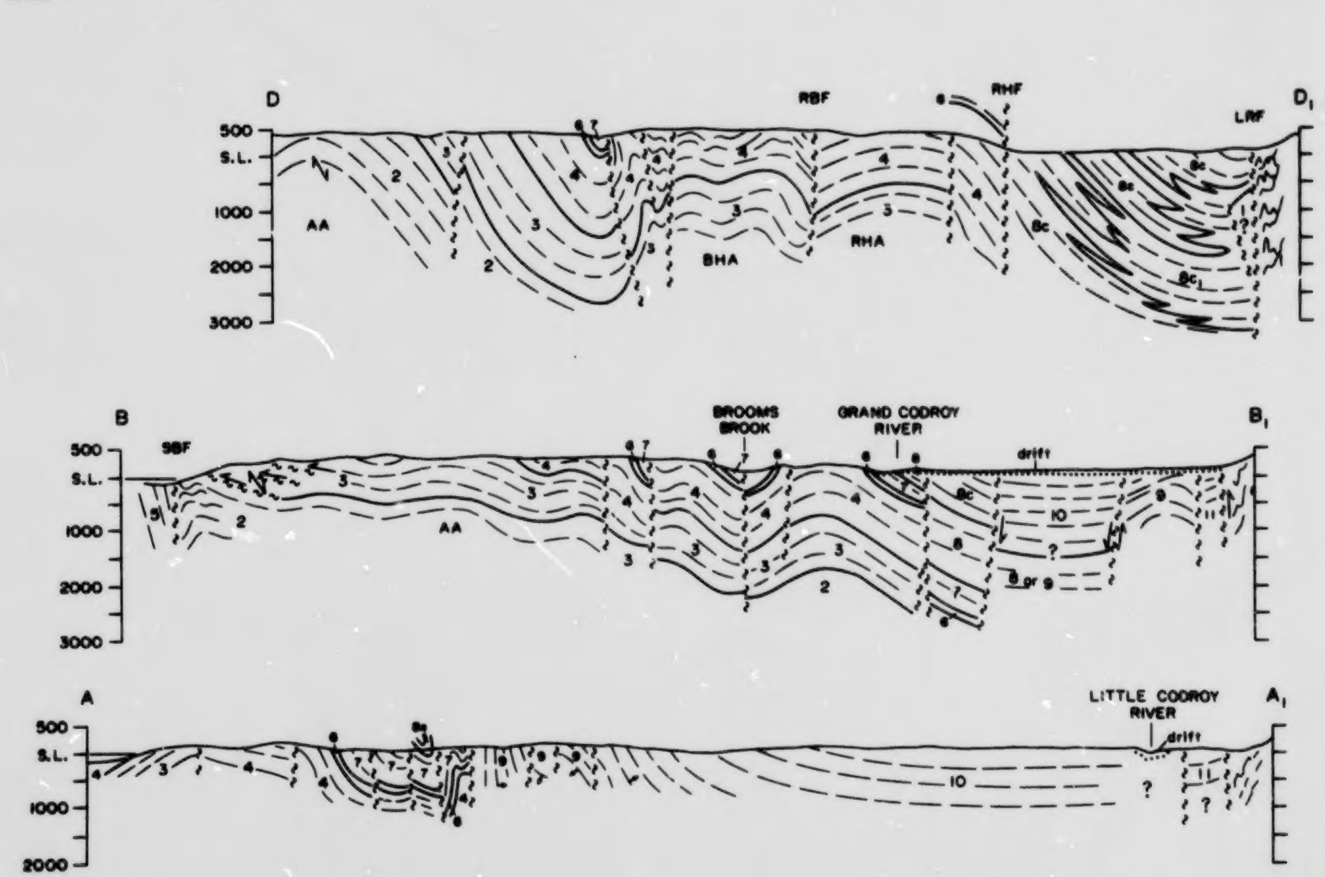
F₁
F
NORTH BRANCH OF CODROY RIVER
SBF
500
S.L.
1000
2000
3000


E
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AA
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RBF
RHF
LRF
3000
BHA
RHA
Bc
Bc₁
B
B₁
BROOMS BROOK
GRAND CODROY RIVER
drift
8 or 9
A
A₁
LITTLE CODROY RIVER
10
?

Figure 43: Structural cross sections across the Bay St. George subbasin in addition to those shown on Newfoundland Department of Mines and Energy, Mineral Development Division Map 82-1. Locations of sections and numbers of rock units are shown on Map 82-1.

Lateral displacement of at least 10 km or oblique-slip of hundreds of metres is probable, depending upon which type of movement occurred on the fault.

Other northeasterly trending faults

The Crabbes Brook fault transects the northwestern margin of the Barachois synclinorium and, together with the Ryans Brook and Ryans Hill faults, trends subparallel to the Long Range fault and dips southeast at 75° to 90°. The Crabbes Brook and Ryans Hill faults both had up to several thousand metres of downthrow to the southeast. Right-lateral movement is also likely on the Crabbes Brook fault as indicated by the associated *en echelon* fold axes in the Barachois synclinorium. Right lateral movement occurred on the Ryans Brook fault, which truncates northeasterly trending *en echelon* fold axes.

Northwesterly trending faults

A number of northwesterly trending faults lie at high angles to the northeasterly trending structures in the Anguille Mountains. They are generally short with only minor offset. Examples can be seen in the southwestern part of the mountains where they locally transect the Ryans Hill and Brooms Hill anticlines and the southwestern closure of the Anguille anticline. Normal, reverse and strike-slip movements, shown by drag folds and slickensides, are postulated to have occurred on minor northwesterly trending faults within the Anguille Mountains. In some instances, structures suggest that left-lateral oblique-slip occurred on some of the minor faults.

Two major northwesterly trending faults with variable displacement occur near the "round valley". The fault planes are poorly exposed but both are considered to be high angle faults. Scissors movement has resulted in downthrow to the southwest at one extremity and downthrow to the northeast at the other extremity. Northeastward downthrow at the southeastern end is indicated by the juxtaposition of Codroy strata against upper Anguille strata, a vertical displacement of perhaps 500 m. However, at the northwest end of the fault near the intersection with the Snakes Bight fault, the fold pattern of rock units at the northeastern fold closure of the Anguille anticline suggest the axial surface of the fold has been uplifted northeast of the fault.

The "round valley" fault appears to strike into a northwesterly trending shear zone in pre-Carboniferous basement rocks of the Long Range Mountains (Figure 42) near South Branch (Chorlton and Dingwall, 1981). As the early tectonic history of the subbasin is interpreted as a "pull-apart" basin, however, this collateral relationship may be simply coincidental.

The northwesterly trending Sheep Brook fault (Riley, 1962), is the boundary fault between Carboniferous strata and the Steel Mountain anorthosite in the northern part of the area. The fault trends northward from Coal Brook to Sheep Brook and then swings to the southeast from Journois Brook along the deeply incised valley of Fischells Brook as far south as the Long Range fault, 4 km east of Big Otter Pond. The presence of this northwest trending fault is supported by variable, steep dips in outcrops of the Brow Pond lentil close to the contact with the anorthosite.

Easterly trending faults

Easterly trending faults are exposed at the coast in the Codroy lowlands and just north of the Anguille Mountains at Shoal Point.

Stormy Point fault

In the Codroy coastal section, the main easterly trending fault is the Stormy Point fault, which trends eastward along the estuary of the Grand

Codroy River. It transects the northeasterly trend of bedding in the inner Codroy lowlands, cutting out the Mollichignick and Overfall Brook Members. The fault splays near the coast so that several consanguineous faults separate the coastal section into a series of fault blocks of upright and overturned strata. The most northerly splay juxtaposes and downthrows upright Woody Cape Formation to the south against folded Codroy Road Formation to the north. In the south, the main branch of the Stormy Point fault downthrows basal Searston Formation on the south side against inverted basal beds of the Woody Cape Formation on the north side.

Between these two main branches, there is a braided splay which separates upright, vertically to subvertically dipping, eastward trending beds of Woody Cape Formation to the north from inverted beds of the Woody Cape Formation to the south (cross-section A, Figure 43). The faults all trend due east and dip 70° to 80° south. The faults are zones several metres wide of crushing, polishing and closely spaced fractures. Minor faults with reverse displacements of a few metres are known to occur. They are sharp and dip between 49° and 71° to the southeast with southern hanging walls overriding northward.

The overturned block between the middle and southern branches of the Stormy Point fault is sigmoidally folded. Steep inverted dips near the middle fault become shallow (20° east) southward in the middle of the block before steepening again towards the southern fault. Downthrow of at least 1000 m to the south is probable on the main faults. South of the fault zone, the Searston Formation is gently warped about a south-southeast axis but it generally strikes eastward and dips to the south. It is cut by some minor northerly trending faults.

Shoal Point fault

The easterly trending Shoal Point fault, north of the Anguille Mountains, downthrows redbeds of the lower Jeffrey's Village Member to the north against folded strata of the Codroy Road Formation. The fault is vertical and has a wide zone of sheared strata. Several parallel faults also cut the Codroy Road Formation to the south of the Shoal Point fault. They disrupt the section in Ship Cove and are associated with local, tight, upright folds.

The inland extent of the fault is speculative. The map shows the fault intersecting the Crabbes Brook fault, but it is possible that it extends eastward into the subbasin north of the Anguille Mountains (see also Belt, 1969). This speculation may be supported by some easterly trending bedding and folds near the Long Range fault at Barachois Brook. If the fault does continue eastward, it possibly caused the northeastern termination of the Snakes Bight fault.

Interpretation of the Structure

The strata of the Bay St. George subbasin appear to have been deformed within a wrench fault regime in which there was right-lateral slip along major northeasterly trending faults. A less likely interpretation is that the subbasin was compressed during crustal shortening which resulted from northwestward overthrusting of the subbasin by crystalline rocks southeast of the Long Range fault. The main evidence in favor of right-lateral wrench movements is the *en echelon* arrangement of fold axes oblique to the Long Range and Snakes Bight faults. It is also supported by the interpretation of northeasterly and northwesterly trending faults, as synthetic and antithetic conjugate faults respectively (cf. Wilcox et al., 1973). Vertical movements probably affected the subbasin later. They are evidenced by (1) bedding attitudes, (2) folds and local slickensiding near and within the Long Range fault zone and (3) northeasterly and easterly trending faults that clearly show large vertical displacements of the stratigraphy.

The geometry of the fold and fault system of the Bay St. George subbasin is summarized in Tables 12 and 13 together with the characteristic geometry of wrench systems according to Wilcox et al. (1973). Structural features of the basin which are in accord with the empirical arrangement of the elements of a wrench system are as follows: (1) the angle of intersection of the northeasterly trending fold axes with the main wrench faults, (2) the orientation of both northeasterly and northwesterly trending faults, and (3) the intersection angle of these faults with each other and the principal wrench faults.

Three factors influenced the progress of the deformation and help explain the local variations from a simple strike-slip model. These are:

1. the presence of stable crystalline basement from Robinsons River northwards;

2. the presence of incompetent rock units in the Anguille and Codroy Groups; and

3. the marked northward thickening of sandstones in the upper formations of the Anguille Group in the northern part of the Anguille Mountains.

The crystalline basement in the north acted as a stabilizing buttress above which relatively simple structures developed in the Carboniferous cover. During deformation incompetent rock units, such as the Snakes Bight and Codroy Road Formations, promoted folding as a mechanism to accommodate shortening and were locally the sites of basal décollement from underlying competent strata. The increased thickness of competent sedimentary rocks in the northern Anguille Mountains is the reason for the consistently open fold structure of that area. In the south, where equivalent strata are thinner and overlie incompetent beds of the Snakes Bight Formation, folds are more common, the cleavage more pervasive and there is associated brittle fracture.

The Anguille anticline

The earliest structure interpreted to have formed in the subbasin was the Anguille anticline. It formed in response to wrench movements, principally along the Long Range fault. Other faults that may also have influenced its formation lie beneath the subbasin and beneath St. George's Bay northwest of this fold. Bedding plane-thrusts formed locally in the Snakes Bight Formation early in the history of the fold, and cleavage developed within the core of the anticline parallel to the axial plane. The axial plane of the fold and the cleavage formed at an angle of 20° to 25° to the main wrench faults. The presence of the incompetent layers probably enhanced the development of the main fold structure and controlled the development of the many other folds to the southwest.

Northeasterly trending synthetic faults

The main northeasterly trending faults are interpreted as synthetic faults within the wrench system. The main synthetic fault, the Snakes Bight fault, formed close to the axis of the Anguille anticline. The general lack of fold axes crossing the fault suggests that most of the smaller *en echelon* folds adjacent to and southeast of the fault formed in response to right-lateral movement upon the fault. The one large anticlinal axial trace north of the fault is probably the original axis of the Anguille anticline. Fault activity during Anguille sedimentation

TABLE 12: *Orientation of folds and faults in the Bay St. George subbasin*

MAIN REGIONAL FAULT	**ORIENTATION**
Long Range fault	*041 to 052*
EN-ECHELON FOLDS	
Anguille anticline	*033*
Other en-echelon folds in the southern Anguille Mountains include Low Brook and Brooms Brook syncline, and Brooms Hill anticline	*034 to 036*
Ryans Hill anticline	*057*
Bald Mountain folds	*043*
Barachois synclinorium	*027 to 030*
Flat Bay anticline	*037*
SYNTHETIC FAULTS	
Snakes Bight fault	*066 to 074*
Ryans Brook fault	*054*
Ryans Hill fault	*054*
Crabbes Brook fault	*037*
ANTITHETIC FAULTS	
"round valley" fault	*104 to 131*
Fault on north side of "round valley"	*146*
Fault near North Branch of Grand Codroy River	*100*
OTHER FAULTS	
Stormy Point fault	*091*
Shoal Point fault	*086*

TABLE 13: *Summary of angular relationship of faults and folds in the Bay St. George Subbasin, with comparison to geometry of wrench fault systems outlined by Wilcox et al. (1973)*

FOLDS

ANGLE OF EN-ECHELON FOLDS TO MAIN WRENCH FAULTS (Wilcox et al. 1973)	**30° ± 15°**
Angle of Anguille anticline to Long Range fault	*19° - 23°*
Angle of Anguille anticline to Snakes Bight fault	*19°*
Angle of en-echelon folds to Long Range fault	*19°*
Angle of en-echelon folds to Snakes Bight fault in a) SW and b) NE of Anguille Mountains	*a) 19°, b) 27°*
Angle of Bald Mountain folds and Ryans Hill anticline to Long Range fault	*15°*
Angle of Barachois synclinorium to Long Range fault	*27°*
Angle of Barachois synclinorium to Crabbes Brook fault	*30°*
Angle of Flat Bay anticline to Crabbes Brook fault	*14°*

FAULTS

ANGLE OF SYNTHETIC FAULTS TO MAIN WRENCH FAULTS (Wilcox et al. 1973)	**12°**
Angle of Snakes Bight fault to Long Range fault in a) SW and b) NE of Anguille Mountains	*a) 0°, b) 25°*
Angle of Crabbes Brook fault to Long Range fault	*11°*
Angle of Ryans Hill fault to Long Range fault	*5°*
ANGLE OF ANTITHETIC FAULTS TO a) MAIN WRENCH and b) SYNTHETIC FAULTS (Wilcox et al. 1973)	**a) 78-90° b) 66°**
Angle of "round valley" fault to Snakes Bight fault	*76°*
Angle of "round valley" fault to Ryans Brook and Ryans Hill faults	*66° - 70°*
Angle of small antithetic faults to Snakes Bight fault	*60° and 82°*
Angle of "round valley" and other antithetic faults to Long Range fault	*52° to 82°*

OTHER FAULTS IN BAY ST. GEORGE SUBBASIN

Angle of Stormy Point fault to Long Range fault	*47°*

(Chapter 3) suggests that a northeasterly trending fault in the basement influenced the formation of the fault and perhaps the position of the Anguille anticline.

Between the Snakes Bight fault and the Ryans Brook fault, internal anticlockwise rotation of the sedimentary succession caused compressive stresses that generated many small folds, some of which locally overturned and were ruptured by reverse faults. Reverse faulting occurred along some synthetic faults where thick sandstone sequences restricted the formation of folds with small wavelength and large amplitude. Large vertical displacements occurred on several of the northeasterly trending faults. These vertical displacements principally occurred during the wrench movements but some may have happened later.

Northwesterly trending antithetic faults

Northwesterly trending faults are interpreted as the antithetic faults of the wrench system. They have variable vertical and lateral displacement (e.g., the "round valley" fault) and may displace both fold axes and synthetic faults. This fact suggests that some of these faults were active later than the synthetic faults.

Easterly trending faults

Easterly trending faults appear to truncate and hence probably postdate all the northeasterly trending structures.

Complex block faulting in the Woody Cape Formation, associated with the Stormy Point fault, suggests a multiple structural history for the fault zone. The simple structure and the lack of *en echelon* drag folds to the south in the Searston Formation do not support any strike-slip motion. Vertical movements with a two-stage history probably occurred. Downthrow on the southern sides of the northern and southern branches of the fault juxtaposed progressively younger formations against each other from north to south. A large, slightly overturned, synclinal drag fold formed in rocks of the Woody Cape Formation north of the southern fault splay. The original syncline was probably later dissected by branches of the Stormy Point fault upon which reverse fault movements occurred. The dislocated, inverted southern limb of this early fold was sigmoidally folded during the later fault movements which placed a southern hanging wall sequence over a northern footwall.

Vertical movements probably occurred upon the Shoal Point fault.

Age and Regional Controls of Deformation

The youngest deformed rocks are dated as Westphalian A to C (Utting, 1966; Hacquebard et al., 1961) suggesting that the main deformation of the subbasin was Late Pennsylvanian or younger. This deformation corresponds in time to the Maritime Disturbance of Atlantic Canada (Poole, 1967). Nevertheless, apart from an unconformity in the Brow Pond lentil, which probably formed during the early stages of the Codroy Group, there is little direct evidence for early deformation during sedimentation in the Bay St. George subbasin. Significant right-lateral displacement of older terranes toward the northwest of the subbasin, however, apparently did occur during deposition of the Anguille Group and both the Snakes Bight and Long Range faults were growth faults. Significant hard-rock deformation of Carboniferous strata of the Bay St. George subbasin did not predate the Westphalian. This is in marked contrast to geologic evidence in the Deer Lake Basin and in Cape Breton. In the Deer Lake Basin, Anguille strata are believed to have been deformed before deposition of the middle Viséan Deer Lake Group and the overlying Howley Beds of Westphalian age (Hyde, 1979a; Hyde and Ware, 1981). This study confirms previous studies of the St

George's Bay area which report that the main deformation was related to movements on the border faults of the basin (Phair, 1949; Belt, 1968b, 1969; Webb, 1969).

Historically, the Bay St. George subbasin and the Maritimes Basin were considered not to have been affected by the Variscan orogeny that deformed the Devonian-Carboniferous strata of Europe and northwest Africa. Paleo-reconstructions of the North and South American, European and North African plate positions in the Carboniferous period, however, suggest that the Maritimes lay in an area that must have been affected by the Variscan orogeny (Schenk, 1971; McKerrow and Zeigler, 1972; Rast and Grant, 1973; Dewey, 1974; Dewey and Kidd, 1974; van Houten, 1976; Leeder, 1976). In these reconstructions, the Variscan orogeny is interpreted to be a result of collision of the North African, North American and South American plates in Late Pennsylvanian - Permian times. More recently, LeFort and van der Voo (1981) showed the Maritime Disturbance within a model of collision and complete suturing between Gondwanaland and Laurussia.

The Variscan and Alleghenian orogens and the Maritimes area have also been interpreted to comprise part of a dextral megashear system that formed in response to transcurrent movements of the African and American-European plates (Arthaud and Matte, 1977). This is an opposite sense of movement from the sinistral wrench model postulated for the Maritimes area of Canada by recent paleomagnetic studies (Van der Voo et al., 1979; Kent and Opdyke, 1978, 1979; Irving, 1979). These authors contend that different pole positions for Maritime Canada's Devonian-Carboniferous rocks compared to those of cratonic North America can be resolved only by major left-lateral drift. In their reconstruction, the Maritimes area was near Florida in the Devonian, possibly attached to a South American plate. It moved a distance of at least 1500 km to occupy its present position by early Permian. Paleopoles for some Carboniferous rocks of the Bay St. George subbasin and for the Late Silurian - Early Devonian Clam Bank Formation (referred to in Kent and Opdyke, 1978; Irving, 1979) appear to conform to those of the displaced poles. Consequently, the subbasin was included in this northeastward moving crustal plate referred to as Acadia (Kent and Opdyke, 1979) or Northern Appalachia (Irving, 1979). However, the writer believes the rocks in the subbasin have always occupied their present position relative to the adjacent provenance areas, i.e. the Cambro-Ordovician platformal rocks of the Appalachian Humber Zone in the north and Lower Paleozoic island arc and granitoid terranes of central Newfoundland to the southeast. This suggests that, if major left-lateral movements occurred, a major wrench system must lie either north or south of the subbasin. The stratigraphic continuity of the Cambro-Ordovician platformal rocks north of the subbasin and apparently across the Strait of Belle Isle to the Grenville basement (Schuchert and Dunbar, 1934; James and Kobluk, 1978; Knight, personal observations) gives no support for the existence of such a wrench zone to the north. In addition, no support for left-lateral slip is seen on the major faults in southwestern Newfoundland. In fact, movements upon these faults and those in Nova Scotia can be demonstrated to have right-lateral, Devonian and Carboniferous movements (Webb, 1969; Keppie, 1979; Bradley, 1982). This implies that, if major sinistral displacement of Maritime Canada occurred in the Devonian and Carboniferous, the main wrench zones lay entirely to the south of Newfoundland and did not affect the onshore Newfoundland Carboniferous.

Structural Conclusions

The structures of the Bay St. George subbasin were produced by right-lateral, strike-slip movements upon the Long Range and related faults. The main deformation occurred in post-Westphalian times, although movements occurred throughout the Carboniferous and controlled sedimentation of the major rock units. The timing of the deformation suggests that it corresponds to the Hercynian orogeny that produced the Variscan fold belt throughout western Europe and North Africa and the Alleghenian orogeny in the southern United States. Dextral transcurrent movements related to this orogeny produced relatively strong deformation (Maritime Disturbance) in a narrow, fault-bounded zone which had previously been the site of the thickest sedimentary accumulation.

The proposed right-lateral wrench system produced *en echelon* fold axes, local thrust faults, décollement and cleavage, and major and minor synthetic and antithetic faults and fractures. The style of deformation was greatly influenced by the thickness and competency of stratigraphic units with incompetent sequences accommodating much of the shortening generated during the wrench movements. The deformation occurred in several stages which are summarized below:

1. Formation of a major northeasterly trending, doubly plunging anticlinorium which contains the Anguille anticline.

2. Development of the Snakes Bight fault along the axis of the anticlinorium. This fault was also active as a growth fault during sedimentation of the Anguille Group, which suggests that it reflects reactivation of a basement fault.

3. Formation of many *en echelon* folds and synthetic reverse faults. Right-lateral strike-slip occurred upon the Snakes Bight fault at this time.

4. Formation of northwesterly trending antithetic faults.

5. Probable vertical readjustments on earlier faults.

6. Late, easterly trending normal faults, e.g. the Stormy Point fault. These may have occurred as the region was uplifted (Schenk, 1978) or as tensional stresses, related to the opening of the North Atlantic, developed during the Triassic (Ballard and Uchupi, 1972; Poole, 1976; Keppie, 1977).

Part 2 - Metamorphism

Restricted subgreenschist dynamothermal metamorphism and local burial metamorphism affected parts of the Anguille Group. This is particularly noticeable in the cleaved red, black and gray beds of the Kennels Brook and lower Snakes Bight Formations. No metamorphism has been noted in the younger rock groups. Metamorphic mineral growth in response to deformation was limited to local zones of intense deformation, particularly the fault zones and the deeper structural parts of the Anguille anticline. Fine grained chlorite and sericite, platy hematite flakes, and coarsely crystalline calcite generally occur. Quartz grains were apparently unaffected. Chlorite forms elongate zones of felted mat along cleavage planes and rock fragments form augen within the foliation in some fault zones. Passive growth of chlorite occurred in the matrices of some of the gray sandstone beds of the Friars Cove Formation on Codroy Island and in the southern part of the Anguille Mountains. This may indicate that burial metamorphism also affected the Anguille Group locally.

CHAPTER 4

ECONOMIC GEOLOGY

The Carboniferous rocks of the Bay St. George subbasin contain a producing gypsum mine at Flat Bay and occurrences of base metals, industrial minerals, evaporites, fossil fuels and uranium. Early exploration in the subbasin began in the 19th century with the discovery of coal. Economic assessment of the coal continued until the 1940's when hope of finding commercial deposits faded. In the 1950's the search had switched to industrial minerals and substantial gypsum reserves were documented in the subbasin. More recently, the subbasin has been explored for base metals and uranium, and the search for salt and potash, begun in the late 1960's, has intensified in recent years. Since the advent of the energy crisis, the coal deposits of southwestern Newfoundland have been receiving renewed attention.

Part 1 - Base Metals and Associated Industrial Minerals

Introduction

Base metal occurrences have long been known in the Carboniferous rocks of the Port au Port Peninsula area of western Newfoundland. However, it was not until 1973 that base metals were discovered in the main part of the Bay St. George subbasin. Copper, lead and zinc mineralization discovered in 1973 (Stevens and Knight, 1974) was subsequently shown to be widespread within the Anguille and Codroy Groups (Knight, 1975, 1976; Douglas and Hsu, 1976).

A basinwide stream sediment geochemical survey was conducted in 1974 by the Newfoundland Department of Mines and Energy (McArthur et al., 1975a and b) to define areas of the subbasin that were anomalous in base metals and industrial metals.

Subsequent mineral exploration, mainly for base metals, included work by Noranda (MacDonald, 1975), Westfield Minerals (1975) and Northgate Exploration (1979 a,b,c).

Description

Base metal and associated mineralization of the Anguille and Codroy Groups occurs in three associations; namely, (a) stratabound vein mineralization within clastic rocks of the Snakes Bight Formation of the Anguille Group, (b) strataform and vein type mineralization associated with the Anguille-Codroy Group contact, and (c) stratabound mineralization in limestones of the Codroy Group at the basal unconformity on the Port au Port Peninsula.

Anguille Group occurrences

Description of Anguille Group occurrences: Small showings of chalcopyrite, sphalerite, galena and pyrite are widely distributed in minor faults, tension joints and fractures that cut the black shales of the Snakes Bight Formation. This mineralization occurs as clots up to several centimetres in size and as disseminations of one or more base metal minerals within narrow, generally <5 cm wide veins of calcite and quartz. Barite may rarely occur. The mineralization in all but one showing (see Table 14, Figure 44) appears to be restricted to veins that cut black shales. Mineralization is apparently absent where the same mineralized vein passes through sandstones that are interbedded with the shales.

Most of the observed showings, none of which are named, occur along the southeast limb of the Anguille anticline and in fault-bounded outcrops in the Codroy - Cape Anguille area (Table 14, Figure 44). Mineralized veins in these showings predominantly trend northwesterly at 305° to 335° although some veins strike due north and others due

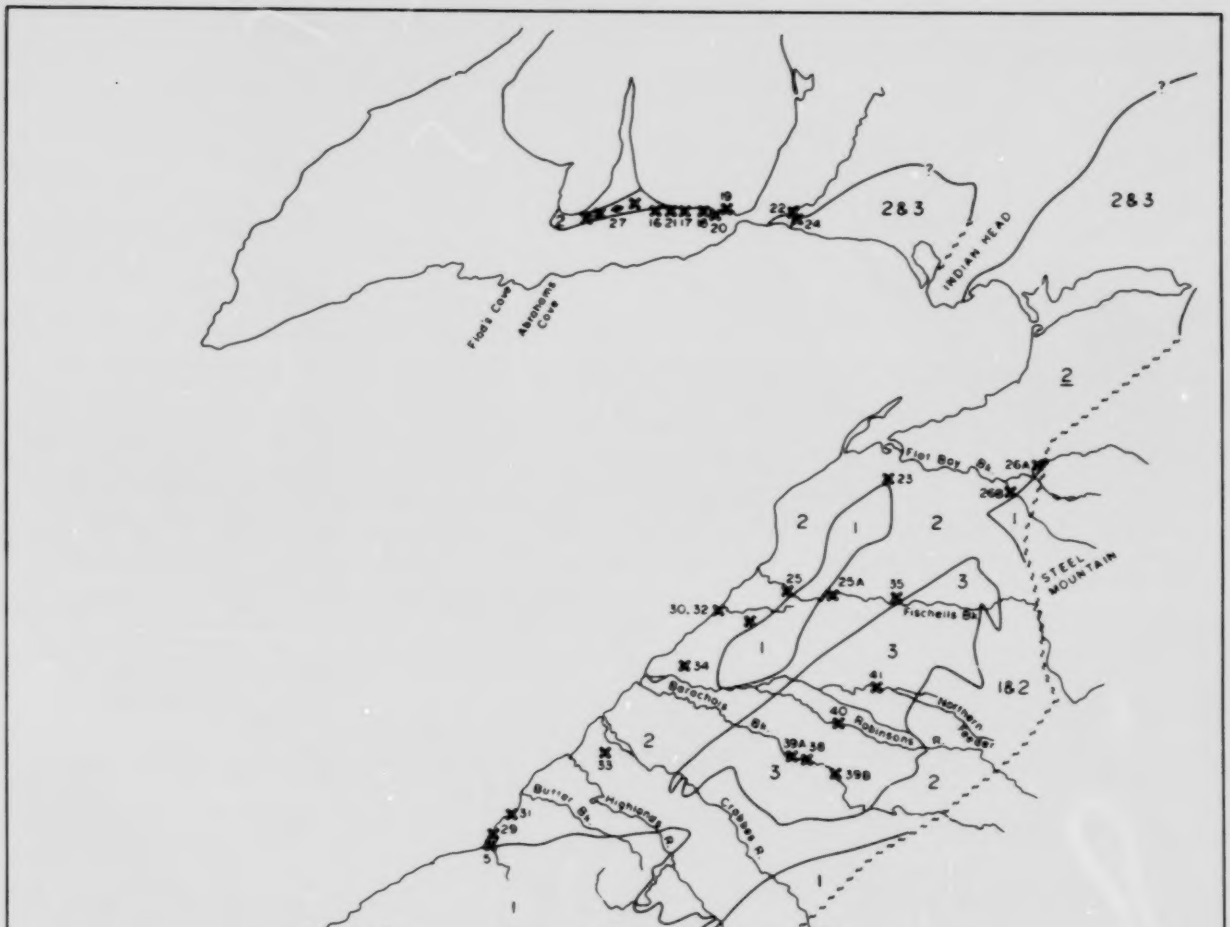
2&3
2&3
INDIAN HEAD
Flat Bay Bk.
STEEL MOUNTAIN
Fischells Bk.
Barachois Bk.
Robinsons R.
Northern Feeder
Crabbes R.
Butter Bk.
Highlands R.
BALD MTN.
ANGUILLE MOUNTAINS
Round Valley
North Branch R.
South Branch R.
Brooms Brook
Ryans Brook
Flat Cove
Abrahams Cove
1&2
LEGEND
3 - BARACHOIS GROUP
2 - CODROY GROUP
1 - ANGUILLE GROUP
8✖ - Locality of showing
✖27✖ - Described in table 14
F✖ - Fluorite
Ba✖ - Barite

Figure 44: Map of localities of mineral showings tabulated in Table 14.

TABLE 14: SUMMARY OF MINERAL SHOWINGS AND DEPOSITS IN THE BAY ST. GEORGE SUBBASIN (Location Map, Figure 46)

1 - BASE METALS AND ASSOCIATED MINERALS

SHOWING NAME	HOST ROCK	MINERALS/METALS	GRADE/TONNAGE	DESCRIPTION/REMARKS
ANGUILLE GROUP				
1 - K 204 (this report)	Black shales - Snakes Bight Formation	Pyrite, Chalcopyrite, Galena		Disseminations in calcite cemented fault breccia, fault orientation 318/74 NE calcite vein 5 cm wide
2 - K 267 (this report)	Black shales - Snakes Bight Formation	Chalcopyrite, Malachite		Disseminations in calcite vein orientated 175/71 W, 2-15 cm wide veins, minerals occur in small cavities lined by clear prismatic quartz
3 - K 268 (this report)	Sandstone - Snakes Bight Formation	Chalcopyrite, Malachite		Disseminations in calcite cemented fault breccia, 3-8 cm wide, trends 310
4 - K 269 (this report)	Black shales - Snakes Bight Formation	Chalcopyrite		Disseminations in calcite/quartz filled vein, trends 342/89 NE
5 - K 296 (this report)	Black shales - Snakes Bight Formation	Chalcopyrite, Sphalerite		Disseminations in calcite vein trending 174, calcite and siderite gangue
6 - K 309 (this report)	Black shales - Snakes Bight Formation	Sphalerite		Disseminations in calcite cemented fault breccia, trends 352/63 E
7 - Cape Anguille (this report)	Black shales - Snakes Bight Formation	Chalcopyrite, Pyrite, Sphalerite, Barite		Disseminations and small clots in calcite veins and fault breccias, trends 255/56 N, 307/70 NE, quartz crystals common
8 - Shoal Point (this report)	Black shales - Snakes Bight Formation	Sphalerite, Pyrite, Chalcopyrite		Small clots and disseminations in calcite veins trending 335
9 - Codroy Breakwater (this report)	Black shales - Snakes Bight Formation	Chalcopyrite, Sphalerite, Pyrite		Small clots and disseminations in calcite veins and fault breccias, minerals occur in cavities in vein trending 310/72 NE, clear quartz crystals also occur
CODROY GROUP				
10 - Noranda showing, North Branch River (MacDonald, 1975)	Limestones - Ship Cove Formation, underlying sandstones of Anguille Group	Hydrozincite, Sphalerite	0.37% Pb, 0.50% Zn	Disseminations in matrix of sandstone, as coatings and small crystals in joint fractures in limestones and sandstones
11 - Sand's pool, North Branch River (this report)	Limestones - Ship Cove Formation	Barite, Sphalerite, Galena, Malachite, Chalcocite?		Disseminations and clots in calcite veins, commonly brecciated, 2-15 cm wide, trend 342/65 E
12 - Trans-Canada Highway road cut, North Branch River (this report)	Limestones - Ship Cove Formation, underlying sandstones of Anguille Group	Barite, Malachite		Joint coatings, disseminations and clots in calcite veins in limestones, 2-5 cm wide, as joint coatings of joints in sandstones
13 - Ryans Brook O'Regans road (this report)	Limestones - Ship Cove Formation, underlying sandstones of Anguille Group	Barite		Disseminations and coatings in veins and joints in base of limestone, 2-5 cm wide, locally breccias, trends 180/75 W, 110/77 S, joint coatings in sandstones
14 - Ryans Brook 750 m upstream from showing 13 (this report)	Limestones - Ship Cove Formation	Barite, Malachite		Pink, white and grey, massive, crystalline and disseminated barite in veins, 2-40 cm wide, one vein 336 cm wide, limestone breccia in same veins, trend 108/85 N, 310/60-80 NE, veins locally have foliated margins, veins subparallel to fault that juxtaposes limestones against Anguille strata
15 - Ship Cove Brook, Ship Cove (this report)	Limestones - Ship Cove Formation	Barite, Chalcopyrite, Malachite, Hematite		Disseminations, clots and coatings in calcite cemented fault breccia and minor fractures, trend 162/74 W

Numerous small vein showings occur in the Ship Cove limestones in the Anguille Mountains. These include fluorite at the NE closure of the Anguille anticline near Highlands River, in streams NW of showing 11 and on Codroy Island. Barite occurs in streams on the north side of Round Valley, west of showing 10.

SHOWING NAME	HOST ROCK	MINERALS/METALS	GRADE/TONNAGE	DESCRIPTION/REMARKS
CODROY GROUP - PORT AU PORT PENINSULA				
16 - Ronan deposit, Hookers Brook (Johnson, 1954)	Sandy & shaly limestones-basal Codroy Group	Barite, Celestite	150,000 tonnes $SrSO_4$ 5-68% $BaSO_4$ 10-85% Ca_2CO_3 8-50%	Wedge-shaped deposit located in north trending Carboniferous paleokarst valley. Minerals intimately mixed. Celestite rich zone in middle of deposit
17 - Gillams Cove (Johnson, 1954)	Sandy & shaly limestones, basal Codroy Group	Barite, Celestite, Minor Galena & Marcasite	17,400 tonnes	Replacement and space filling in limestone breccia. Deposit lies in basal Codroy limestones within north trending paleo- karst valley. Equal percentages of barite and celestite. Calcite/aragonite gangue
18 - Aguathuna Quarry (this report)	Shaly limestone Basal Codroy Group	Celestite, Barite, Marcasite		Space filling and replacement, crystalline minerals in porous dolomitic limestone
19 - Lead Cove (Douglas and Hsu, 1976; McArthur and Knight, 1974)	Limestone breccia, shaly limestone - Basal Cordoy Group	Galena, Marcasite, Pyrite	Cu-trace, Pb-0.08%, Zn-0.14-0.18%, Ag-trace	Replacement, vein and space filling in limestone breccia in north trending paleo-karst valley, unconformably upon Ordovician limestones. Radiating marcasite-galena in veins. Some drilling
20 - Bellmans Cove (Douglas and Hsu, 1976; McArthur and Knight, 1974)	Limestone breccia, shaly limestone - Basal Codroy Group	Sphalerite, Marcasite, Pyrite, Barite		Space filling in limestone breccia in paleo-karst valley unconformably above Ordovician limestones. Main sphalerite showings on east side of cove

21 -	*Miners Cove (Douglas and Hsu, 1976; McArthur and Knight, 1974)*		*Galena, Marcasite, Barite*		*Limestones lying unconformably within paleo-karst valley. Adit into mineralized zone 150 m above road*
22 -	*Romaines Brook (this report)*	*Limestones - Ship Cove Formation*	*Barite*		*Vein, joint coating in limestone*

On the south side of Port au Port Peninsula at Piccadilly Harbour, Abrahams Cove and Fiod's Cove, steeply to vertically dipping, northeast trending veins host galena, sphalerite, marcasite and pyrite. The veins, probably of Carboniferous age, are filled by vari-colored calcite layering suggesting they are speleothem deposits. The veins cut Ordovician limestones and occur near outcrops of red Carboniferous sedimentary breccias

II - EVAPORITES

GYPSUM-ANHYDRITE

23 -	*Flat Bay Gypsum Mine (McKillop, 1969; Douglas and Hsu, 1976)*	*Codroy Road Formation*	*Gypsum, Anhydrite*	*Recoverable reserves estimated in 1968 to stand at 38 x 10^6 tonnes. Total reserves estimated at 156 x 10^6 tonnes $CaSO_4 \cdot 2H_2O$-80-95%*	*White to gray gypsum, well bedded gently folded, locally faulted, dips increase on east limb of Flat Bay anticline. Anhydrite replaces gypsum downwards, minor salt in fractures, overburden 1-58 m, 3 quarries, present production rates 0.5 to 0.8 x 10^6 tonnes per annum*
24 -	*Romaines Brook (McKillop, 1955, 1959)*	*Codroy Road Formation*	*Gypsum*	*2.25 x 10^6 tonnes Good quality*	*White; horizontally bedded. 597 m of drilling in 1955 and 183 m in 1970. Gypsum is 26 m thick*
25 -	*Fischells Brook (A - west; B - east) (Flintkote, 1972; McKillop, 1969)*	*Codroy Road Formation*	*Gypsum*	*25A - 10 x 10^6 tonnes 25B - no estimates*	*25A - white to locally pink, well bedded, dipping west at 30-35. Cliff exposures near railway bridge. 29 drill holes with total length of 975 m. 25B is same gypsum lying 2.5 km upstream in east limb of Flat Bay anticline; no additional information*
26 -	*A Sheep Brook B Coal Brook (Johnson, 1954)*	*Codroy Road Formation*	*Gypsum*	*Combined tonnage of 10 x 10^6*	*White and light gray; anhydrite apparently minor (Baird, 1954). Beds overturned, dipping 65-80 SE. Many shear surfaces*
27 -	*Boswarlos-Piccadilly (Douglas and Hsu, 1976)*	*Codroy Road Formation*	*Gypsum, Anhydrite*		*White and pink gypsum, blue-gray anhydrite, 12-24 m thick, 8.4 m drift cover. Red beds and conglomerate associated*
28 -	*Plaster Pond, east of Heatherton-railway station (Ross, 1947)*	*Codroy Road Formation*	*Gypsum, Anhydrite*	*0.5 x 10^6 tonnes*	*White pure gypsum, thickness 200 m in two beds. Drilling over 300 m strike length*
29 -	*Ship Cove (this report; Douglas and Hsu, 1976)*	*Codroy Road Formation*	*Gypsum*		*Two beds, each 20-30 m thick, in folded sequence with black limestones, red and grey mudstones and shale. White, yellowish and grey, massive and selenitic gypsum. Evaporite zone continues inland for 7 km to Butter Brook*
30 -	*Rattling Brook (this report; Bell, 1948; Douglas and Hsu, 1976)*	*Jeffreys Village Member, Robinsons River Formation*	*Gypsum*		*Two beds each 2-3 m thick, white and red colored. Bedding dips 45 NW. Gypsum zone d (Bell, 1948). Interbedded with dolomites and red beds*
31 -	*Plaster Cove (this report; Bell, 1948; Douglas and Hsu, 1976)*	*Jeffreys Village Member, Robinsons River Formation*	*Gypsum*		*White, massive and selenitic gypsum, 45 m thick. Overlies green siltstones and sandstones. Thick glacial drift cover*

Gypsum is known from a large number of isolated showings around the margins of the Anguille Mountains. These occur at several places along Crabbes River, on Barachois Brook, Highlands River near the Trans-Canada highway, on North Branch River and in the "round valley", Codroy lowlands. Other outcrops occur near Ryans Brook, along Brooms Brook and along the shore and inland of Codroy and Woodville. Gypsum is also known near Northern Feeder and Robinsons River.

CELESTITE

32 -	*Rattling Brook (this report)*	*Jeffreys Village Member, Robinsons River Formation*	*Celestite*		*25 cm bed overlying gypsum on shore. Usually covered by beach gravels*

HALITE-POTASH

33 -	*St. Fintans drill hole (Hooker Chemical Corporation, 1973)*	*Jeffreys Village Member, Robinsons River Formation*	*Halite, Sylvite, Carnallite, Anhydrite*	*Potash zones and analyses given in Table 15*	*White, red and gray halite, K_2O zones distributed through salt, mudstone interbeds common, sylvite in upper zones, carnallite in lower zones, K zones 0.5-6.29 m thick. Total salt section 120 m thick. Salt beds decrease downwards*
34 -	*Robinsons drill hole (Hooker Chemical Corporation, 1972)*	*Jeffreys Village Member, Robinsons River Formation*	*Halite, Sylvite, Carnallite, Minor Anhydrite*	*Potash values given in Table 15*	*White and gray salt, red sylvite and carnallite, K_2O zones, 1-4 m thick, distributed throughout the drill hole. Upper salt sequence 208 m thick, lower salt sequence 71 m thick, middle sequence of black shales containing salt beds and potash. Sylvite +/– carnallite in higher K zones, carnallite in lower K zones*
35 -	*Fischells Brook drill hole (Hooker Chemical Corporation, 1968a)*	*Jefferys Village Member, Robinsons River Formation*	*Halite, Sylvite, Carnallite, Polyhalite, Anhydrite, Gypsum*	*Halite reserves - 7,000 x 10^6 tonnes NaC1 - 80-98%; K_2O values in Table 15*	*Clean clear, neutral, gray and white salt, light orange to red sylvite +/– carnallite in zone 4-5 m thick at top of salt section, $CaSO_4$ increases downwards. Minor red mudstone interbeds*

34 - Robinsons drill hole (Hooker Chemical Corporation, 1972)	Jeffreys Village Member, Robinsons River Formation	Halite, Sylvite, Carnallite, Minor Anhydrite	Potash values given in Table 15	White and gray salt, red sylvite and carnallite, K_2O zones, 1-4 m thick, distributed throughout the drill hole. Upper salt sequence 208 m thick, lower salt sequence 71 m thick, middle sequence of black shales containing salt beds and potash. Sylvite +/– carnallite in higher K zones, carnallite in lower K zones
35 - Fischells Brook drill hole (Hooker Chemical Corporation, 1968a)	Jefferys Village Member, Robinsons River Formation	Halite, Sylvite, Carnallite, Polyhalite, Anhydrite, Gypsum	Halite reserves = 7,000 x 10^6 tonnes NaC1 = 60-98%; K_2O values in Table 15	Clean clear, neutral, gray and white salt, light orange to red sylvite +/– carnallite in zone 4-5 m thick at top of salt section, $CaSO_4$ increases downwards. Minor red mudstone interbeds
III - COAL				
36 - Coal Brook, South Branch (Hayes, 1949; Hayes and Johnson, 1938; Maclean, 1946)	Barachois Group	Jubilee seam - 1.5-7.0 m thick, Begonia seam - 0.6 m thick	95,000 - 195,000 tonnes, clean coal	Associated with fireclays, shale beds and gray sandstones. Coals, possibly lenticular deposits, coal section bounded by faults. Abandoned mine
37 - Campbell's Brook (Hayes and Johnson, 1938)	Barachois Group	30 cm seam		Interbedded shales and thin coals; small adit. Near fault?
38 - Joe McKay's Brook, Barachois Brook (Hayes, 1949; Bryan, 1938; Hayes and Johnson, 1938; Douglas and Hsu, 1976)	Barachois Group	Cleary seam - 0.9 m thick, Jukes seam - 1.54 m thick, Furlong seam - 0.92 m thick	0.5 to 0.95 x 10^6 tonnes Fixed carbon - 54-62%, moisture and volatiles - 30-34%, ash - 4-10%, sulphur - 1-4%. High volatile B bituminous coal	Associated with fireclays, shale and gray sandstones. Seams exposed in core of Barachois synclinorium. Thickness of seams varies, many shale partings in coals. Youngest seams in group. 5 thin seams, each 10-56 cm thick, noted in drill holes below upper seams
39 - Murray (39A) and Tom Diamond (39B) Seams Barachois Brook	Barachois Group	1-2 cm coal in 60 cm of shale		Two seams are believed to be lateral equivalents of each other on the west and east limbs of the Barachois synclinorium. Seams believed older than those at Joe McKay's Brook
40 - Howley Seam, Robinsons River (Howley, 1913; Bryan, 1938)	Barachois Group	30 & 33 cm coals in shale bed	Fixed carbon - 61-63%, moisture & volatiles - 31%, ash - 5-7%	Coal disturbed by faulting
41 - Shears Seam, Northern Feeder (Howley, 1913)	Barachois Group	35 m coal?	Good quality?	
URANIUM-COPPER				
42 - Grand Codroy River, 1.5 km west of South Branch (this report; Dunsmore, 1977b)	Sandstones - Mollichignick Member, Robinsons River Formation	Uranium	U 107 ppm	In gray, planar-stratified sandstones (lithofacies C, Robinsons River Formation). No visible uranium minerals, 5-6x background radiation. Fine detrital plant material plentiful
43 - Grand Codroy River, 3 km west of South Branch (this report; Dunsmore, 1977b)	Sandstones - Mollichignick Member, Robinsons River Formation	Uranium, Malachite	U 30-34 ppm, Cu 775 ppm	In gray, planar-stratified micaceous sandstones (lithofacies C, Robinsons River Formation). High radioactivity occurs at locally developed basal scour into underlying gray mudstones and in a semicircular arch within sandstone. Arch is rooted to the basal scour. It is 1 to 3 m diameter and 5-10 cm wide. Fine plant material common
44 - Stephens Brook (this report)	Sandstones - Mollichignick Member, Robinsons River Formation	Uranium, Malachite		Thick, crossbedded gray sandstones, (lithofacies D). Scattered pebbles and plant fossils, visible malachite, no visible uranium but 5-6x background radiation
45 - Grand Codroy River (this report; Dunsmore, 1977b)	Sandstones - Mollichignick Member, Robinsons River Formation	Uranium	U 13.1 ppm	Thick crossbedded gray sandstones, rich in plant fossils. 5-6x background radiation
46 - Grand Codroy River (this report)	Sandstones - Mollichignick Member, Robinsons River Formation	Uranium, Malachite	U 7.4 ppm, Cu 1650 ppm	Thick crossbedded gray sandstones (lithofacies D, Robinsons River Formation). Associated with abundant gray mudclasts and plant fossils above scour at base of sandstone
47 - Grand Codroy River (this report)	Overfall Brook Member Robinsons River Formation	Uranium, Copper	U 23-323 ppm, Cu 3000 ppm	In gray carbonaceous mudstones and siltstones, intercalated with thick beds of pink arkosic pebbly grits and sandstones
48 - Kennedy Point (this report)	Sandstones - Searston Formation	Malachite		Associated with abundant mudclast and carbonaceous plant fragments at the base of a thick upward fining sandstone units

west. The northwest trending veins mostly dip 70° to 75° northeast. A number of lead and zinc stream- and lake-sediment geochemical anomalies (McArthur et al., 1975a) found in the Anguille Mountains correlate with the outcrop distribution of the Snakes Bight Formation.

Interpretation of Anguille Group occurrences: The mineralization in the Snakes Bight Formation infilled tension and shear fractures that cut the shales of the formation. The ore fluids either may have originated from a deep hydrothermal source or may have been mobilized from the host sediments (Boyle, 1963). The latter interpretation is attractive for the following reasons:

i) the mineralization, although widespread, is minor;

ii) the minerals occur predominantly in fractures cutting black shales; and

iii) pyrite laminae and concretions are present in the black shales.

This suggests that the black shales, which were deposited in a reducing lacustrine environment, were the source of the metals. Release of metalliferous fluids occurred during compaction and dewatering of the sediments.

Codroy Group occurrences

Base metal and industrial minerals occur within the limestones of the Ship Cove and Codroy Road Formations. Mineralization, particularly copper, also occurs in the clastic sediments of the Codroy Group but, because of its common association with uranium, it is discussed later.

Occurrences in the Ship Cove Formation and the immediately underlying sediments of the Anguille Group: The contact between the Codroy and Anguille Groups is an important stratigraphic horizon for mineralization. This is consistent with the evidence from the rest of the Maritimes Basin (Binney, 1975), where mineralization occurs in the basal limestones of the Windsor Group and as much as 15 m or more into the underlying Horton Group clastic sediments (Binney, 1975; Kirkham, 1978).

In the Bay St. George subbasin, mineralization occurs in the Ship Cove limestones and in the underlying sandstones of the Anguille Group. Mineral showings are particularly widespread in the Anguille Mountain area although no significant accumulations have been discovered to date. Mineralization occurs in thin calcite veins only a few centimetres wide that cut the Ship Cove Formation. Minerals include barite, chalcopyrite, chalcocite, galena, sphalerite and pyrite associated with hematite, malachite and fluorite. The chief mineral in the veins in most showings is barite which is best seen at Ship Cove, Ryans Brook and in a road cut along the Trans Canada Highway immediately north of the North Branch River. The minerals generally occur as centimetre-sized clots, and as disseminations and joint surface coatings. Mineralization, in particular barite, extends downward for several metres along similiar structures into the underlying sandstones. However, in rare instances, as for example the Noranda showing, base metal mineralization is disseminated within the sandstones themselves.

Base metal showings with more than one metal are found in the North Branch River area. Here the limestones and the immediately underlying Anguille sandstones are black in color rather than gray as in areas to the south. The black color of the sandstones of this area also contrasts with red colors found in sandstones to the north. The main lead-zinc mineralization in this area occurs in the Noranda showing on the south side of the North Branch River, near the Trans Canada Highway. There, a zinc and lead soil anomaly

(MacDonald, 1975) reflects mineralization in black sandstones that underlie the Ship Cove Formation limestones. Analyses of the sandstones showed they contained up to 0.37% lead and 0.50% zinc (MacDonald, 1975). The zinc occurs in the matrix of the sandstones and in small veinlets. Hydrozincite coats some rock surfaces and sphalerite occurs in fractures in the overlying limestones. No visible galena was noted. The other base metal showing in the North Branch area is at Sandy's pool on the North Branch River, 2 km west of the Trans Canada highway. The showing consists of several thin calcite veins that cut perpendicularly through the Ship Cove Formation limestones, and host crystals and small clots of sphalerite, galena and chalcopyrite.

Minor malachite, chalcocite and barite occur in veins and along joints in the Ship Cove Formation and the Anguille Group sandstones at Ship Cove, and in the Trans Canada highway road cut 1 km north of the North Branch River. Some chalcocite is also disseminated in the sandstones, and hematite was noted at Ship Cove.

Although barite is generally widespread, the best showings occur along Ryans Brook, 750 m upstream from the O'Regans road. Here barite occurs in several veins, most a few centimetres to 40 cm wide, cutting the limestones of the Ship Cove Formation close to an important fault. The fault downthrows the limestones against green-gray sandstones of the Anguille Group. The fault strikes 300° and dips 45° to the north. Close to the fault surface, barite veins strike 110° and dip 85° south. The veins make up a zone several metres wide composed mostly of limestone cut through by numerous 1 to 7 cm wide veins of calcite and barite. Within this zone is a vein 366 cm thick composed of massive, crystalline, pinkish-white barite and gray and white, foliated barite and calcite. Alignment of limestone fragments occurs in the foliated margin of the vein. Other mineralized tension fractures and veins up to 20 cm wide occur upstream within 30 m of the fault. They include barite and calcite with disseminated chalcopyrite and malachite. Barite is also common in the Ship Cove Formation limestones that outcrop on the same brook at O'Regan's but here no thick veins are developed, only coatings and filling within joints.

Results of a stream sediment geochemical survey (McArthur et al., 1975a, b) indicate that the areas underlain by the Spout Falls Formation immediately below the Ship Cove Formation are anomalous in barium and lead, in the Bald Mountain area. An induced polarization survey (Westfield, 1975) covering a high barium stream sediment anomaly (up to 2250 g/t) at the northwest side of Bald Mountain failed to delineate any indications of mineralization. Stream samples in this area are anomalous in lead, containing more than 98 g/t lead (McArthur et al., 1975a) although no galena occurrences have been found. Other geochemical anomalies in the Anguille Mountains, such as strontium at the north end of Ryans Hill overlooking "round valley", are considered to be related to mineralization located near the Codroy-Anguille contact. Structural cross-sections of the Ryans Hill area suggest that the Ship Cove Formation probably capped this ridge.

Interpretation of occurrences in the Ship Cove formation and the immediately underlying sediments of the Anguille Group: The mineralization associated with the Anguille-Codroy Group contact includes both stratiform and vein mineralization. Low grade mineralization associated with the contact compares to mineralization at the equivalent Horton-Windsor contact in the Maritimes (Binney, 1975; Kirkham, 1978) and suggests a synsedimentary or early post-depositional origin for the deposits. Vein mineralization possibly resulted from remobilization of the synsedimentary minerals or was precipitated by ore fluids derived from either a deep hydrothermal source or by compaction of the underlying Anguille Group (Boyle, 1963). Development of foliation in the margins of barite veins near the fault at Ryans Brook suggests that this mineralized body formed while the rocks were being deformed. Other veins elsewhere in the subbasin appear to be simple tension fractures that opened after the main phase of deformation had been completed.

A syn- or early post-depositional origin for the mineralization suggests that the mineral-forming process was closely linked to the depositional setting of the Ship Cove Formation. In the Bay St. George subbasin, the limestones of the Ship Cove Formation are interpreted as shallow subtidal to intertidal algal flat carbonates. The main lead-zinc showings in the subbasin occur near North Branch River, whereas barite, fluorite and some copper are distributed in several localities elsewhere in the Anguille Mountains. The lead-zinc showings are associated with dark colored, bituminous, pyritic and carbonaceous laminites interpreted as lower intertidal flat deposits and with dark gray, reduced sandstones of the top of the Anguille Group.

Close association of large sedimentary copper deposits and evaporites is recognized in many parts of the world (Renfro, 1974). Kirkham (1978) has indicated the similarity between the Horton-Windsor contact and the Permian Zechstein/Rotliegendes contact (Kupferschiefer) in central Europe and elsewhere in the world. Renfro (1974) suggested that this relationship is linked to the sedimentary processes of sabkhas and presented a model for precipitating metals close to contacts such as the Anguille-Codroy. Evaporative pumping (Hsu and Siegenthaler, 1969) initiated by surface evaporation on the sabkha draws marine waters laterally through the carbonate flats causing dolomitization and displacive growth of nodular sulfates in the limestones (Shearman, 1966). Fresh groundwaters, which act as oxidizing, low pH, high Eh, metal-bearing solutions, may pass through porous clastics that extend landward beyond the sabkha but also underlie the carbonates. The metal-bearing fluids are also drawn upward by the evaporation and the metals are precipitated at the base of the carbonate in a reducing H_2S-rich layer and within underlying reduced sandstones. Renfro (1974) noted that the metallogenic process on the sabkha would be influenced by longevity of process, quantity of available reducing agent, amount and metal content of source water, and shifting sedimentary facies.

The lack of dolomitization and displacive nodular evaporites in the Ship Cove Formation suggests that the sabkha process was generally ineffective except in the north of the subbasin, e.g. at Flat Bay and Romaines Brook. Restricted sabkha processes in the subbasin may have been due to early lithification and to the shaly limestone, at the top of the formation, which may have formed an effective impermeable barrier to the passage of fluids. Even though evaporites occur extensively in the overlying Codroy Road Formation, no brines appear to have refluxed downward (Deffreyes et al., 1965) to dolomitize the limestones (see also Kirkham, 1978).

Recently, Kirkham (1978) proposed that the widespread ores at the Horton-Windsor contact formed early in the sedimentary history of the basal Windsor limestones. Adopting Geldsetzer's (1978) interpretation of the Macumber limestones as subtidal algal laminites which blanketed the sea floor of a rapidly drowned, inland, desert basin, Kirkham postulated that the mineralization formed at oxidation/reduction boundaries that occurred at or crosscut the stratigraphic boundary. Metals were released from associated redbeds of the Horton Group by an oxidizing paleohydraulic regime within porous Horton clastics. The metals were precipitated as the fluids encountered the bituminous limestones of the Macumber Formation and/or the reduced portion of the underlying oxidized clastics. Fluid motion was possibly controlled by a hydraulic head formed in nonmarine siliciclastics which fringed the marine basin and passed basinward immediately beneath the limestones.

The base metal showings of the Ship Cove Formation probably formed by a mechanism similar to that suggested by Renfro (1974). Facies analysis of the Ship Cove Formation and overlying rocks suggests tidal flats blanketed by prograding fine terrigenous clastics occurred in the southwestern part of the subbasin. Metal-bearing water passed into the Anguille siliciclastics, and a hydraulic regime was maintained by evaporitic pumping or by a hydraulic head. Metals were precipitated in the more reduced lithologies of the formation, which were locally restricted to the North Branch River area. Fortuitously, organic-rich, lower intertidal, algal-mat carbonates were deposited above highly reduced Anguille sandstones that were deposited in a transition zone between red fluvial sandstones to the north and gray, deltaic-lacustrine beds to the south. This relationship of younger to older facies is lacking elsewhere in the subbasin and may have been a fundamental factor controlling base metal deposition. Ineffective sabkha processes, thinner organic-rich limestones and increased argillaceous and shaly content in limestones in other Anguille sections of the Ship Cove Formation, plus lack of suitably reductive sandstone in the Anguille Group, also restricted mineralization.

Occurrences near the northern margin of the Bay St. George subbasin and Port au Port Peninsula: Galena, sphalerite, marcasite, barite and celestite occur in limestones of the lower Codroy Group on the Port au Port Peninsula. The mineralization occurs in basal Windsor A shaly and sandy limestones and shelly limestones that unconformably overlie Lower Paleozoic rocks. The mineralization is developed as pore and cavity fillings in shelly bioherms and brecciated limestones and as replacements of the Codroy limestones (Johnson, 1954). Vein-controlled barite similar to that elsewhere in the basin also occurs in the Ship Cove Formation on Romaines Brook. The deposits of the Port au Port Peninsula lie in north trending, steep-sided, fault-controlled, Carboniferous paleokarst valleys that were cut in Ordovician limestones before the deposition of the basal Codroy sedimentary rocks. Gypsum and some redbeds overlie the limestones near Piccadilly Bay. Barite and celestite with minor galena and marcasite occur at Gillams Cove, Aquathuna quarry and Hoopers Brook (McArthur, 1973; McArthur and Knight, 1974). Galena-marcasite deposits with some barite occur in Lead Cove, Bellmans Cove and Miners Brook (McArthur, 1973; McArthur and Knight, 1974).

Only the geology of the mineralized prospects at Gillams Cove and Hoopers Brook is known to date and this is summarized here from descriptions of Johnson (1954). Both prospects consist of a mixture of celestite and barite. The Gillams Cove deposit contains an ore body at least 45 x 75 x 2 m in size that is estimated to contain approximately 17,400 t of combined celestite-barite ore. Johnson described the Gillams Cove prospect as consisting of "a mixture of crushed and shattered limestone in irregular bouldery masses together with crystalline aggregates of celestite that enclose smaller amounts of barite, calcite and aragonite." The bluish celestite appears to dominate the ore. The mineralization occurs in flat-lying sandy and shaly limestones of the Codroy Group which sit within a paleo-valley in Ordovician limestones. The prospect is covered by overburden. It extends northward to the mouth of the brook and Johnson seems to have implied that it continues seaward beneath Port au Port Bay.

A larger prospect occurs at Hoopers Brook and was named the Ronan deposit by Johnson (1954). It is an open ended, wedge-shaped body at least 75 x 105 x 1-12 m in size which is calculated to contain at least 150,000 t of mixed sulfate ore. The mineralization sits in a north trending Carboniferous paleo-valley within Ordovician limestones. Carboniferous rocks that host the mineralization are again sandy and shaly limestones which intertongue with mineralized rock. The latter consists of blue granular celestite and white, radiating, platy, crystalline celestite enclosed within a groundmass of finely crystalline aragonite and celestite. Finely granular celestite is also intimately mixed with fine barite and lenses and masses of crystalline celestite are enclosed within either white and pinkish, massive barite or occur within brecciated limestones. Celestite also fills vugs, cavities and veins in the limestones. Aragonite and calcite are intermixed in the ore body with some gypsum and detrital(?) quartz and kaolinite residues.

Analyses of ore and drilling sludge (Johnson, 1954) suggest that $SrSO_4$ in the Ronan deposit is subordinate to barite. A narrow north trending celestite-rich zone occurs in the middle of the deposit with $SrSO_4$ values varying from 30% to 68% over a thickness of 3 to 5.5 m and $BaSO_4$ rarely reaching more than 10%. Mineralization surrounding this zone is barite-rich with values varying from 40% to 85% over thicknesses of 3.5 to 10.5 m. The thickest barite occurs at the northern, open, down-dip end of the deposit where it contains less than 5% $SrSO_4$.

Some detailed logs of drill holes through the prospect suggest that the mineralization replaced the upper part of thinly bedded, shaly and sandy oncolitic limestones such as compose the basal Codroy limestones seen on the shore at Boswarlos. In a small outcrop of shelly limestone preserved in the Aguathuna limestone quarry, the celestite-barite mineralization occurs as open-space fillings in the shelly limestones. The Aguathuna deposit is believed to be laterally equivalent to the thinly bedded limestones at Boswarlos, both deposits belonging to basal Windsor subzone A (von Bitter and Plint-Geberl, 1982). Johnson suggested open-space fillings in the Ronan deposit formed later than the replacement-type mineralization. Such open-space mineralization is, however, common in several other minor mineral showings on the north side of the Port au Port Peninsula where shelly limestones lie directly on Paleozoic basement in paleokarst valleys. Consequently it is thought likely that both space-fill mineralization in shelly limestones and replacement-type mineralization, such as dominate the Ronan and Gillams Cove deposits, occurred coincidently.

To date, little is known of the nature and distribution of galena, sphalerite, pyrite and marcasite on the Port au Port Peninsula. At Miners Brook, Bellmans Cove and Lead Cove, these base metals occur as massive lenses, veins and as disseminations in buff colored shelly and brecciated limestones which rest unconformably upon older limestones within narrow Carboniferous paleokarst valleys. Minor celestite and barite accompanies the base metals. An exploratory adit was driven into the Miners Brook showing 150 m upstream of the road crossing Miners Brook (McArthur and Knight, 1974). Lead appears to be the most common of the base metals in these deposits.

Interpretation of occurrences near the northern margin of the Bay St. George subbasin and the Port au Port Peninsula: The age of the mineralization in the Codroy Group on the north side of the Port au Port Peninsula is not known. Celestite deposits in Cape Breton occur in a similar setting. They lie close to a basement contact associated with sulfate evaporites and carbonates; the celestite is believed to have formed diagenetically within collapse breccias and the associated evaporite and carbonate lithofacies (Crowell, 1971). Diagenesis and ore emplacement possibly followed karstification of the succession during the early Windsor (Forgeron, 1977; Boehner, 1981b). A similar origin is possible for the Ronan and the Gillams Cove celestite-barite deposits. Dix (1981) suggested that the barite and celestite formed diagenetically after burial of the limestones beneath younger Carboniferous strata.

If the unconformity at the base of the Codroy Group is a control of mineralization, then the northern margin of the Bay St. George subbasin has good potential for more discoveries of both base metals and industrial minerals.

Other showings

Minor copper showings have been observed in limestones of the Codroy Road Formation. Most occurrences are indicated by bornite-like surface tarnishes, but minor disseminated chalcocite, chalcopyrite and pyrite have been observed in the Black Point limestone and in similar limestones near Bald Mountain. Galena is reported in a carbonate unit in the upper part of the Jeffrey's Village Member at Shallop Cove (Fong, unpublished data).

Base Metal Potential in the Bay St. George Subbasin

To date, no important base metal discoveries have been made in the subbasin. The best prospects found in Carboniferous rocks of western Newfoundland occur on the north side of the Port au Port Peninsula. They are hosted by carbonates that unconformably overlie a pre-Carboniferous basement ridge. In mainland Nova Scotia and Cape Breton, base metals are found in similiar geologic situations where carbonates, including bioherms, and evaporites onlap or rest unconformably upon basement, eg. Gays River Pb-Zn deposit, Nova Scotia and Kaiser celestite deposit, Cape Breton. Substantial lead deposits have also been discovered in basal sandstones of the Windsor Group that unconformably overlie Precambrian basement rocks in a narrow basin at Yava, Cape Breton. Exploration away from basin margins, both in Nova Scotia and Newfoundland, has only discovered widespread low grade disseminated mineralization associated with the basal Macumber and Ship Cove Formations of Nova Scotia and Newfoundland (Binney, 1975).

Clearly then, rocks with the best potential for economic mineralization lie along the north margin of the subbasin, near Stephenville, east of the Indian Head complex and perhaps on the northeastern margin of the subbasin north of the Steel Mountain anorthosite.

Basin configuration of the northern edge of the subbasin has been interpreted to be irregular during deposition of upper Anguille and lower Codroy Groups. Basement highs may have occurred at Flat Bay and near the Steel Mountain anorthosite. Other highs probably include the Indian Head "promontory". Biohermal carbonate buildups may have developed along the flanks of the highs which were separated by narrow, marine seaways comparable to the situation at Gays River. It is thus possible that prospective biohermal buildups of lower Codroy age could be located at depth between the Flat Bay inlier and the Indian Head "promontory", and between the Flat Bay inlier and the Steel Mountain anorthosite.

Part 2 - Evaporites

Deposits of gypsum, anhydrite, celestite and sodium and potassium salts are extensive in the Codroy Group throughout the Bay St. George subbasin. They are comparable to the equally extensive deposits hosted by the Windsor Group of the Maritime provinces.

Gypsum - Anhydrite

Gypsum occurs in the Codroy Road and Robinsons River Formations at four stratigraphic intervals. A producing mine occurs in the Codroy Road Formation at Flat Bay and is operated by Flintkote of Canada. These intervals were called zones a, b, c, and d by Bell (1948) but should not be confused with his stratigraphic subzones A, B, C, D, and E of the Windsor Group (Bell, 1929). Zone "a" lies in the lower part of the Codroy Road Formation while zone "b" occurs at the top of the same formation interbedded with limestones such as the Black Point and Cormorant limestones (Bell, 1948). These two zones are the thickest and most extensive in the basin and zone "a" contains the Flat Bay mine. Zones "c" and "d" occur in the Jeffrey's Village Member of the Robinsons River Formation. They are poorly exposed and are found only in the St. George's Bay area. Zone "d" gypsum is associated with limestones and a celestite bed.

The gypsum deposits were studied by Baird (1951, 1954, 1959) and McKillop (1959) who identified several major deposits in the northern part of the basin. These deposits belong to the Codroy Road Formation and include a deposit of over 38 million tonnes at Flat Bay, approximately 10 million tonnes at Fischells Brook, 2.25 million tonnes at Romaines Brook and 10 million tonnes at Sheep and Coal Brooks near Steel Mountain. These deposits have the economic advantages of size, accessibility, simple structure, good quality and proximity to shipping facilities. Deposits elsewhere in the basin are less well known and are generally considered to be less attractive economically because of structural complications and distance from shipping facilities.

All of the large deposits in the northern part of the basin are generally flat-lying to moderately dipping, with the exception of the Sheep and Coal Brook deposits. The Flat Bay deposit lies at the northern closure of the gently plunging Flat Bay anticline, and the Fischells Brook deposit occurs in the west limb of this same structure. The Romaines Brook deposit is flat-lying and lies along the northern margin of the basin. The Sheep and Coal Brook deposits dip steeply away from the Precambrian basement near Steel Mountain. The steep dips are the result of major normal faulting in this area between sedimentary rocks of the Codroy and Anguille Groups and Precambrian basement rocks.

The gypsum deposits are of good quality. Impurities include beds and remnants of light gray to buff dolomite and dolomitic shale and solution structures filled with glacial drift. Minor salt occurs in the deposits (McKillop, 1959) and can result in salt springs above subsurface deposits. Collapse structures and faults cause local steepening of dips in the deposits.

Gypsum is underlain by anhydrite in the northern deposits of the basin and the contact is usually marked by a transition zone of interlayered gypsum and anhydrite. The contact observed in the Flat Bay mine is irregular. There, a large buttress of anhydrite rises steeply up through the gypsum on the northeastern limb of the Flat Bay anticline. The gypsum also appears to be much thinner over the crest of the anticline, thickening on the limbs. This thinning is probably the result of glacial scouring and suggests a preglacial origin of the gypsum, probably by alteration of anhydrite by downward percolation of groundwater (McKillop, 1959; Baird, 1959). Gas pockets in the anhydrite were encountered during drilling (McKillop, 1957b). Salt content increases downward in the transition zone and varies between 0.1% to 0.6% NaCl.

Numerous unnamed and unstudied occurrences of gypsum occur around the periphery of the Anguille Mountains in the Codroy Road Formation. There, the gypsum is generally steeply dipping, and continuity is affected by folding and numerous faults. The gypsum varies from finely crystalline to coarse and selenitic. Flow banding is common and black, bituminous, dolomitic limestone fragments are scattered throughout many of the deposits. The deposits are generally poorly known and no tonnage estimates have been made.

Two minor gypsum deposits occur in the Jeffrey's Village Member of the Robinsons River Formation near Plaster Cove and Rattling Brook, St. George's Bay. The deposit at Plaster Cove is 45 m thick (Bell, 1948) and consists of white, massive, finely crystalline gypsum and coarse selenite. The geographic extent of the deposit is not known as the gypsum is surrounded by thick glacial drift. The younger deposits of gypsum at Rattling Brook occur in two beds 2 to 4 m thick. They are interbedded with carbonates, celestite and fine redbeds. The gypsum is red to white, consisting of selenite porphyroblasts set in finely crystalline gypsum that locally exhibits radiating chevron structures. Bedding occurs in the base of the gypsum beds. No data concerning tonnage, geographic extent or quality of the commodity is available for the deposits. No gypsum deposits from the Jeffrey's Village Member have been identified in the Codroy lowlands.

Celestite

Celestite occurs on the coast of St. George's Bay near Rattling Brook and in shelly limestones on the north side of Port au Port Peninsula at Hoopers Brook, Gillams Cove, Aquathuna Quarry and at Bellmans Cove. The celestite at Rattling Brook occurs as a 25 cm bed associated with gypsum, limestone and red sediments of the Jeffrey's Village Member of the Robinsons River Formation. This bed, which strikes parallel to the shore, dips steeply seaward. It lies beneath beach gravels and is not generally exposed; its lateral extent and quality are not known. The celesite bed has not been found anywhere else in the basin. Isolated strontium geochemical anomalies (McArthur et al., 1975b) do occur near Uncle Joes Pond at the expected stratigraphic position of the bed. Nonetheless, there is no evidence of its presence in the exposed section along Fischells Brook. Strontium stream- and lake-sediment geochemical anomalies also occur along Dribble Brook and in some other isolated areas underlain by the Codroy Group, indicating that celestite may also occur in the northern area of the basin. These anomalies may not be related to the Rattling Brook celestite bed.

The deposits on the north shore of the Port au Port Peninsula were discussed above under base metals and associated mineralization.

Salt Deposits

Salt deposits hundreds of metres thick are known from drilling at St. Fintan's, Robinsons River and Fischells Brook (Hooker Chemical Corporation, 1968a, 1972, 1973). The stratigraphic position of all the salt deposits within the Codroy Group has not been determined with certainty, although the deposits at St. Fintan's and Robinsons River have been placed in the lower part of the Jeffrey's Village Member, Robinsons River Formation. These two salt deposits are stratified and affected by only minor salt flow and structural complications; they are believed to be laterally equivalent to a siliciclastic succession below the Fischells limestone (Windsor subzone B of Bell, 1948) on Fischells Brook (Figure 19). The Fischells Brook deposit was affected by salt movements and it is not known if (1) it is equivalent to the other two deposits, (2) if it was deposited in the Codroy Road Formation (Windsor subzone A) or (3) if it was deposited in both the Codroy Road Formation and in the lower part of the Jeffrey's Village Member.

History of investigation

The presence of salt was first indicated by salt springs (Hayes and Johnson, 1938; Baird, 1951) at scattered localities in the St. George's Bay area. A gravity survey (Blanchard, 1953; Verrall, 1954a and b) located several gravity lows (Figure 45). Follow-up work was undertaken on the Robinsons River, Fischells Brook and St. Fintan's anomalies in 1967 (Hooker Chemical Corporation, 1968b). In 1968, the first salt was proven at Fischells Brook by drilling (Hooker Chemical Corporation, 1968a). More gravity studies outlined an additional 13 gravity lows in the St. George's Bay (Figure 45) and Codroy areas (Hooker Chemical, 1971). Follow-up work was recommended on anomalies at Robinsons, St. Fintans', St. Teresa, Stephenville Pond and the mouth of the Little Codroy River.

The two latter anomalies have never been drilled as they have been interpreted to be caused by thick Pleistocene cover (Hooker Chemical Corporation, 1971). Drilling at St. Fintan's and Robinsons confirmed salt at depths of about 235 m, slightly shallower than depths calculated from the gravity survey (Hooker Chemical Corporation, 1971). In each instance, the centres of the gravity lows were drilled and no exploration of the flanks was undertaken.

The St. Teresa anomaly was drilled by Amax Exploration (1976) and the hole passed through 936 m of red sediments probably of upper Codroy age; it encountered no salt. In 1976, Amax Exploration also drilled the northeast flank of the Fischells Brook anomaly, in which salt had previously been proven (Hooker Chemical Corporation, 1968). The hole, which was only 600 m northeast of Hooker Chemical's successful hole, penetrated 900 m of Barachois Group and some Codroy Group strata. Fractures and polished and graphitic surfaces are common in the core and it is probable that a major high angle fault, which is believed to be the northward extension of the Crabbes Brook fault, occurs between the two holes. Recent drilling of the Fischells Brook deposit by Pronto Exploration Ltd. and Camflo Mines (R.P.F. Syndicate, 1980) was successful in encountering salt with encouraging intersections of potash-bearing zones (Northern Miner, 1980).

Description

Salts up to 390 m thick and containing several zones of potash mineralization were proven in the three successful early holes (Figure 46). Anhydrite and gypsum are present in these deposits and overlie and underlie the main salt horizons. Clastic sediments include gray shales and mudstones and brown and red siltstones and mudstones; some brown dolomites and limestones are also present. Layering and bedding in the cores dip between 27° and 38° in the St. Fintan's core and from 30° to 55° in the Robinsons core. The bedding dips in the Fischells Brook core are mostly about 20° to 30° in the upper 415 m of the hole and between 50° and 60° below this level. Thicknesses of the drill holes are shown in Figure 46. Thicknesses referred to in the text were recalculated from data in drill hole logs using observed dips.

The St. Fintan's salt is 120 m thick, of which the basal 70 m is poor in salt. Two salt horizons occur at Robinsons River, the upper being 184 m, and the lower 54+ m thick. They are separated by 100 m of anhydrite and black, halite-bearing mudstones with some salt beds. In the Fischells Brook deposit, 390 m of salt was penetrated and the base was not reached. The salt was entered at 256 and 233 m (true depth) from the top of the St. Fintan's and Robinsons holes respectively and at 387 m (true depth) in the Fischells Brook hole. Glacial overburden 46 and 61 m thick occurs at the top of the Robinsons and Fischells Brook holes.

The salt is banded, massive and fine to coarsely granular, and varies through white, gray, neutral, red, pink and orange in color. Large crystals are common and salt-filled fractures cut both salt and interbedded shale units.

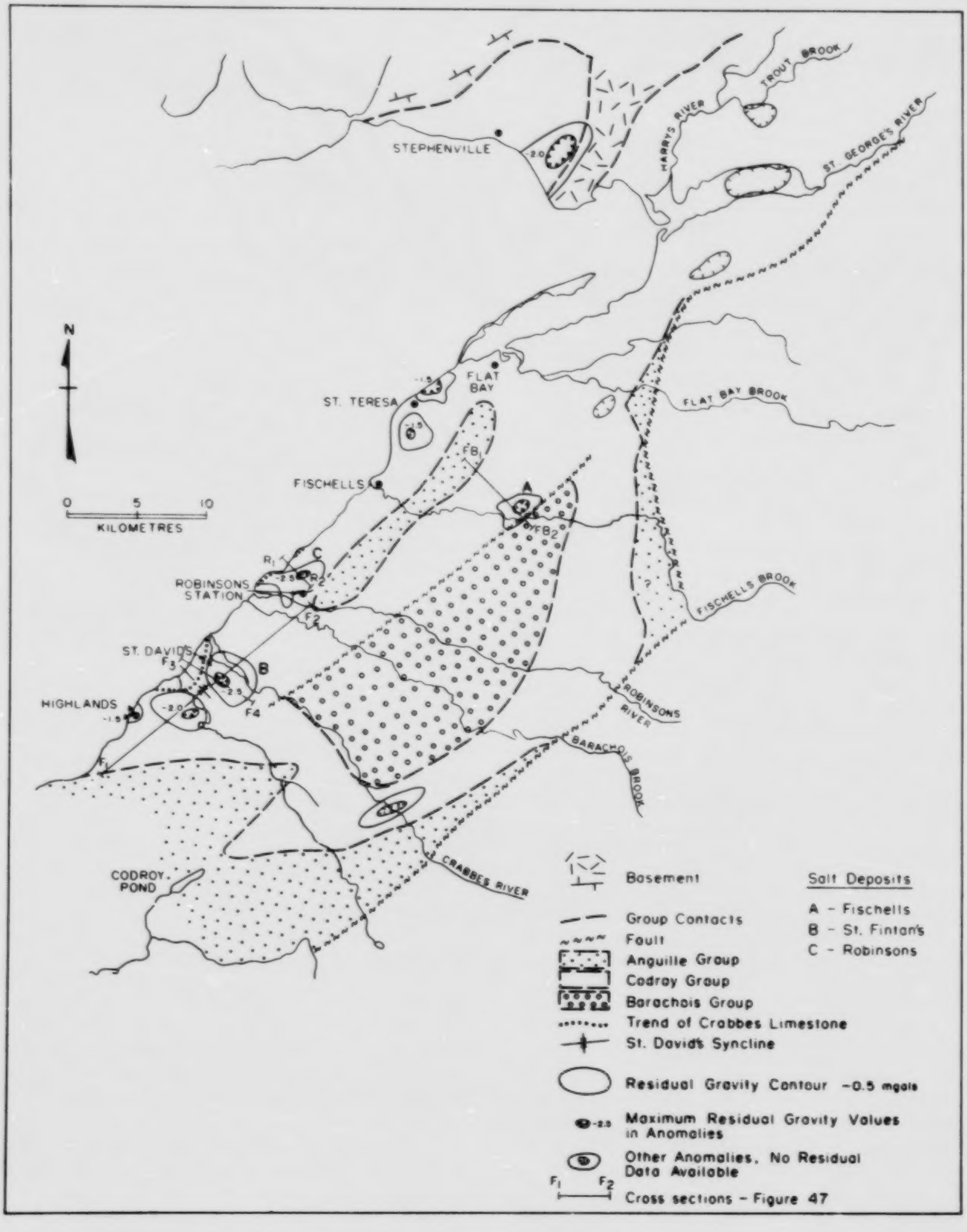
STEPHENVILLE
-2.0
HARRYS RIVER
TROUT BROOK
ST. GEORGE'S RIVER
N
0 5 10
KILOMETRES
ST. TERESA
FLAT BAY
-1.5
FLAT BAY BROOK
FISCHELLS
FB1
A
FB2
FISCHELLS BROOK
R1
C
-2.5
R2
ROBINSONS STATION
F2
ST. DAVIDS
F3
B
-2.5
F4
HIGHLANDS
-1.5
-2.0
F1
ROBINSONS RIVER
BARACHOIS BROOK
CRABBES RIVER
CODROY POND
Basement
Group Contacts
Fault
Anguille Group
Codroy Group
Barachois Group
Trend of Crabbes Limestone
St. David's Syncline
Residual Gravity Contour -0.5 mgals
Maximum Residual Gravity Values in Anomalies
Other Anomalies, No Residual Data Available
F1 F2
Cross sections - Figure 47
Salt Deposits
A - Fischells
B - St. Fintan's
C - Robinsons

Figure 45: Distribution of gravity lows in the St. George's Bay lowlands.

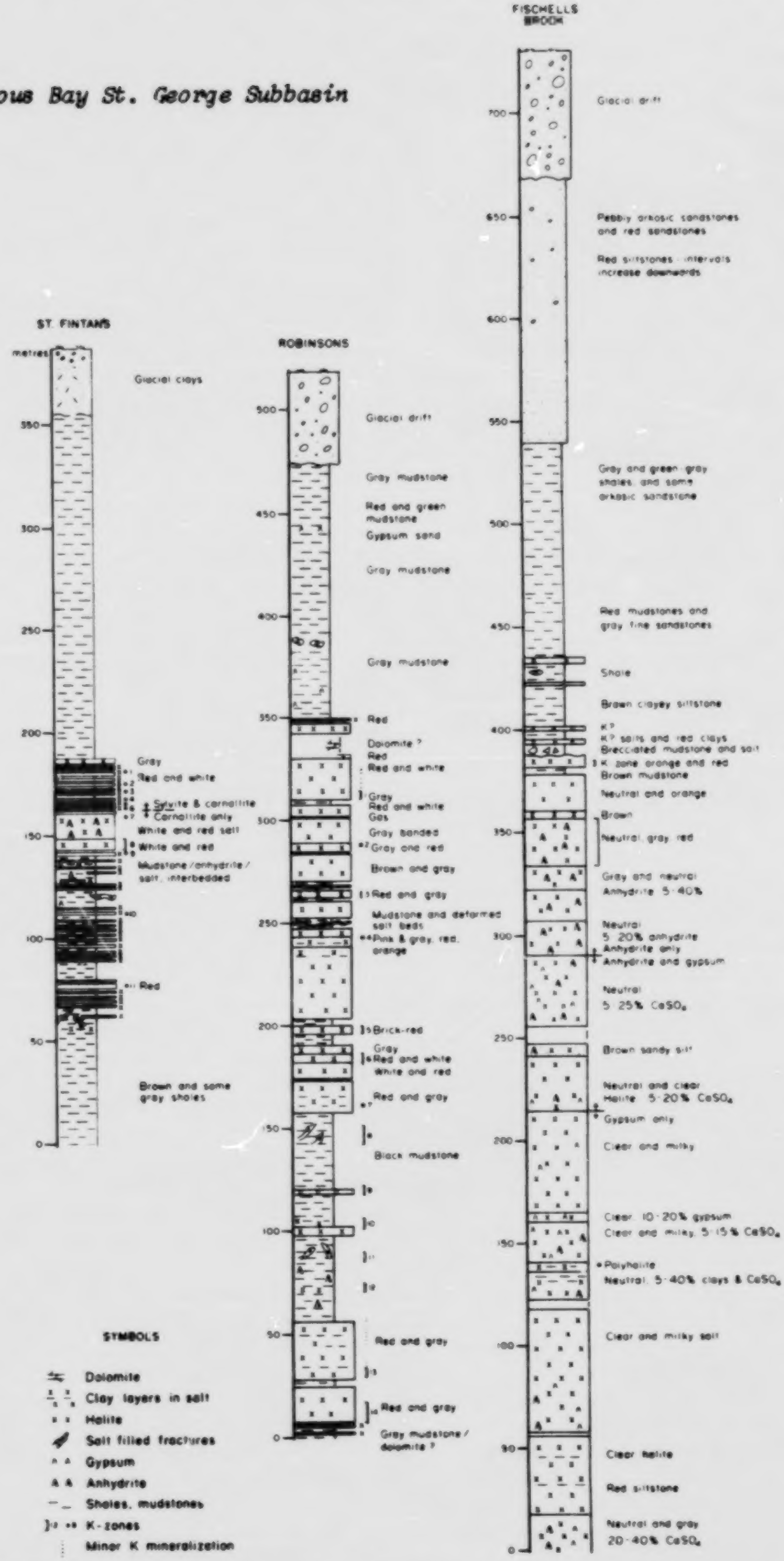
ST. FINTANS
metres
350
300
250
200
150
100
50
0
Glacial clays
Gray
Red and white
Sylvite & carnallite
Carnallite only
White and red salt
White and red
Mudstone/anhydrite/salt, interbedded
Red
Brown and some gray shales
ROBINSONS
500
450
400
350
300
250
200
150
100
50
0
Glacial drift
Gray mudstone
Red and green mudstone
Gypsum sand
Gray mudstone
Gray mudstone
Red
Dolomite ?
Red
Red and white
Gray
Red and white
Gas
Gray banded
Gray and red
Brown and gray
Red and gray
Mudstone and deformed salt beds
Pink & gray, red, orange
Brick-red
Gray
Red and white
White and red
Red and gray
Black mudstone
Red and gray
Red and gray
Gray mudstone/dolomite ?
FISCHELLS BROOK
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Glacial drift
Pebbly arkosic sandstones and red sandstones
Red siltstones - intervals increase downwards
Gray and green-gray shales, and some arkosic sandstone
Red mudstones and gray fine sandstones
Shale
Brown clayey siltstone
K?
K? salts and red clays
Brecciated mudstone and salt
K zone orange and red
Brown mudstone
Neutral and orange
Brown
Neutral, gray, red
Gray and neutral
Anhydrite 5-40%
Neutral
5-20% anhydrite
Anhydrite only
Anhydrite and gypsum
Neutral
5-25% CaSO₄
Brown sandy silt
Neutral and clear
Halite 5-20% CaSO₄
Gypsum only
Clear and milky
Clear, 10-20% gypsum
Clear and milky, 5-15% CaSO₄
Polyhalite
Neutral, 5-40% clays & CaSO₄
Clear and milky salt
Clear halite
Red siltstone
Neutral and gray
20-40% CaSO₄
SYMBOLS
Dolomite
Clay layers in salt
Halite
Salt filled fractures
Gypsum
Anhydrite
Shales, mudstones
K-zones
Minor K mineralization

Figure 46: Sections compiled from logs of drill holes through St. Fintan's, Robinsons and Fischells Brook salt deposits.

The potash zones include sylvite (KCl), carnallite ($KMgCl_3 \cdot 6H_2O$), and polyhalite ($K_2CaMg(SO_4)_4 \cdot 2H_2O$). The sylvite appears to occur in the higher potassic zones and carnallite composes the lower potassic zones. The sylvite and carnallite generally occur disseminated in halite in these zones. Sylvite varies from fine to coarsely crystalline and from clear to white to rusty red in color. Carnallite is generally red in color. The polyhalite is crystalline and in some instances fibrous; it also occurs as nodules mixed with halite in mudstone units. Gray and white anhydrite and gypsum occur as nodules, lumps and layers, particularly in the deeper part of the salt deposits.

The potassic horizons generally occur throughout the thickness of the salt in the St. Fintan's and Robinsons deposits (Figure 46). In the Fischells Brook deposit, however, potash occurs at the top of the salt and over a thickness of about 6 m (Hooker Chemical Corporation, 1968a). The potassic zone in this hole is readily identified by gamma ray logs and has a sylvite content of more than 5%. The zone was also identified in a whipstock hole drilled off from the main hole in order to test the mineralization. Here within a broad zone 4.64 m thick is a K-rich layer 1.5 m thick that contains 20 to 25% sylvite. This zone overlies a 3 m zone averaging 10% sylvite, in which the sylvite occurs as 2 to 5 cm thick layers alternating with halite. Values for the best zones are shown in Table 15. The best beds have K_2O values of up to 19%. In secondary zones, K_2O varies from 0.1% to 16%. The salt in the zone is clean with <1% insolubles. It is pale orange to gray in color in the main hole but the potassic salts are brick red in the whipstock hole. A zone 4.32 m thick of minor K mineralization occurs 130 to 140 m from the bottom of the main hole. It is believed to be principally composed of polyhalite (Hooker Chemical Corporation, 1968a).

In the Robinsons deposit (Hooker Chemical Corporation, 1972), potassic zones 1 to 8.7 m thick are interspersed throughout the deposit (Figure 46). A total thickness of 69.83 m of K mineralization occurs in 14 horizons. This is approximately 20% of the total salt section; the percentage increases to 30% however when additional zones of secondary K mineralization are included. Sylvite, together with deliquescent carnallite, occur in the upper 5 zones. Carnallite occurs in mineralized zones below this level. K_2O values vary between 2.7% and 6.3% in the 14 horizons. Horizons 8 to 12 occur in salt beds and within halitic mudstones of the middle siliciclastic section of the Robinsons hole. The potash salts occur in red and dark gray salts including brick red sylvite and deliquescent red carnallite. Eleven zones, 0.5 to 6 m in thickness, with between 3.5% to 9% average K_2O, occur in the St. Fintans deposit (Hooker Chemical Corporation, 1973) (see Figure 46 and Table 15). The mineralization occurs in interlayered and intermixed red and white crystalline salts. Mg content is generally less than 0.1% in the upper six zones of the deposit, suggesting the presence of sylvite. Increase in Mg to 1% to 3% below zone 6 suggests that carnallite is the potassic mineral phase in zones 7 to 11. The K-salt is generally brick red in these lower zones. Here K_2O values average 3% but may be as high as 8%.

Good quality salt occurs in these deposits; impurities vary between 3% and 15%. The salt beds intersected to date in the St. Fintan's deposit, however, are apparently rarely thicker than 3 m, and are separated by thin mudstones and anhydrite. In the Fischells Brook deposit, anhydrite and gypsum increase in the lower half of the deposit, reaching 15% to 40% in some layers. The sulfate-rich layers alternate with sulfate-free halite layers.

	THICKNESS IN METRES	K%	Mg%	K_2O%	$MgCl_2$%	INSOL. %	REMARKS
				ST. FINTANS			
1.	2.78	3.3-7.6	0.05-0.1	4.0-9.11			Red and white salt, brown salt at top
2.	1.32	5.7	0.03-0.05	6.8-6.9			White salt
3.	3.31	3.1-6.6	0.02-0.4	3.7-8.0			Dark, white and red salt
4.	0.66	4.5	0.07	5.4			White and red salt
5.	0.52	5.1	0.06	6.2			
6.	0.52	4.9	0.11	5.9			
7.	3.31	3.0-5.4	1.0-1.2	3.7-6.5			White salt, carnallite
8.	4.3	2.5-5.3	1.1-2.9	3.0-6.4	4.3-16.6	3.4-23.8	White salt and potash
9.	0.49	6.8	0.45	8.29			Mud and potash
10.	1.41	5.3	1.6	6.4			Mud and potash
11.	3.97	1.3-5.7	0.3-1.2	6.9	5.7	19.91	Mud, potash, red salt
				ROBINSONS			
1.	3.08	5.23	0.01	6.3	0.04	0.71	Red and gray salt
	Zone 1 lies within a 14.84 m thick zone with minor potash, containing K - 1.3-2.4%, Mg - 0.01-10.2%, K_2O - 1.4-2.9%, $MgCl_2$ - 0.04-0.47%, insolubles - 0.03-1.09%						
2.	2.87	3.34	1.3	4.02	5.1	5.2	Dark gray and brick red salt
3.	2.75	2.26	0.20	2.72-5.3	0.78-6.3	1.4	Red salt, deliquescent
4.	1.06	2.66	0.23	3.2	0.90	3.7	Red salt
	Zone 4 is underlain by 2.96 m with minor potash containing K_2O - 1.4%, $MgCl_2$ - 1.38%						
5.	3.11	4.9	1.4	5.9	5.5	2.1	Dark gray and red salt
6.	4.13	3.7	0.86	4.5	3.4	0.5	Salt; deliquescent
7.	1.56	4.82	1.51	5.8	5.8	2.04	Red salt
8.	8.69	2.51-2.78	1.0-1.32	3.02-3.55	3.2-3.8	32.2-47.9	Vein salt in mudstone
9.	3.79	4.07	1.36	4.9	5.32	3.54	Salt bed in mudstone
	Zone 9 is underlain by minor potash for 4.45 m, containing K_2O - 1.88%, $MgCl_2$ - 3.09%, Insolubles - 42.5%						
10.	4.45	2.85	1.44	3.43	5.64	36.09	Salt and mudstone
	Zone 10 is overlain by minor potash in mudstone, containing K_2O - 1.46%, $MgCl_2$ - 3.72%, Insolubles - 70.27%						
11.	4.45	2.55	0.27	3.07	1.06	59.0	Salt in mudstone
12.	4.45	1.96	0.80	2.36	3.13	43.45	
13.	4.24	2.3	0.57	2.77	2.23	11.79	Intimately intermixed red and gray salt
14.	8.48	2.4-2.9	0.6-0.8	2.9-3.5	2.3-3.3	3.2-3.9	
	Minor potash occurs in two other zones in the drill hole. The first lies between zones 5 and 6 where brick-red salt injects a mudstone. The second is 12.72 m thick and lies 4.24 m above zone 13. It consists of K_2O -1.4-1.6%, $MgCl_2$ - 1.1-1.4% and 1.3-16.3% insolubles						
				FISCHELLS BROOK			
	Main Hole						
	5.96	–	0.008-0.028	0.1-7.1	–	0.2-1.1	Gray to light orange halite, sylvite and carnallite
	A potash-rich zone 0.77 m thick occurs near the base of this wide mineralized zone.						
	Whipstock hole—potash-zone equivalent to main hole.						
	4.64	contains two potash-rich zones					
1.	0.86	4.4-15.6	–	5.3-18.8	Average K_2O = 13.4%		Brick-red sylvite,
2.	1.54	0.61-15.8	–	0.7-19.0	Average K_2O = 8.3%		Halite and clay
	Other minor potash zones between these two rich horizons include 0.25 m of 7.2% K_2O and 0.08 m of 15.5% K_2O and 0.08 m of 5.0% K_2O.						

Table 15: Summary of thickness and chemistry of K-rich zones in salt deposits of the St. George's Bay lowlands. Numbers correspond to zones in drill log sections illustrated in Figure 46.

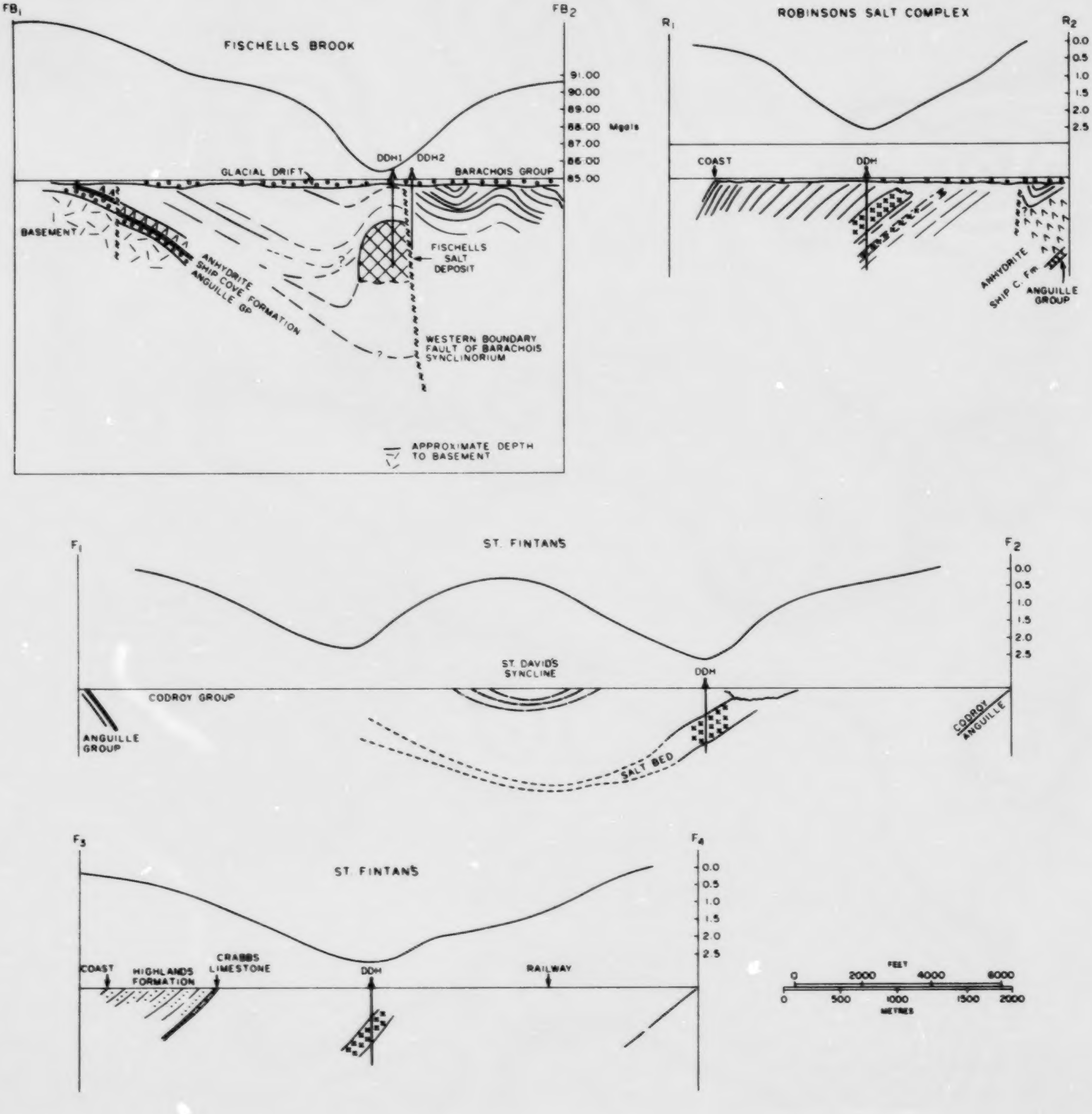
FB1
FB2
FISCHELLS BROOK
91.00
90.00
89.00
88.00 Mgals
87.00
86.00
85.00
DDH1
DDH2
GLACIAL DRIFT
BARACHOIS GROUP
BASEMENT
ANHYDRITE
SHIP COVE FORMATION
ANGUILLE GP
FISCHELLS SALT DEPOSIT
WESTERN BOUNDARY FAULT OF BARACHOIS SYNCLINORIUM
APPROXIMATE DEPTH TO BASEMENT
R1
R2
ROBINSONS SALT COMPLEX
0.0
0.5
1.0
1.5
2.0
2.5
COAST
DDH
ANHYDRITE
SHIP C. FM.
ANGUILLE GROUP
F1
F2
ST. FINTANS
ST. DAVID'S SYNCLINE
DDH
CODROY GROUP
ANGUILLE GROUP
SALT BED
CODROY
ANGUILLE
F3
F4
ST. FINTANS
COAST
HIGHLANDS FORMATION
CRABBS LIMESTONE
DDH
RAILWAY
FEET
0
2000
4000
6000
0
500
1000
1500
2000
METRES

Figure 47: Residual gravity and simplified structural cross sections of three salt deposits in the St. George's Bay lowlands. Sections lines shown on Figure 45.

Interpretation

The residual and Bouguer gravity maps of the three main salt deposits were examined and reinterpreted in the light of the geological information available from this study (Figure 47). The shapes of the anomalies at St. Fintan's and Robinsons River suggest west to northwestward dipping bedded deposits rather than salt plugs. This is particularly evident in the northeast-southwest cross-section of the St. Fintan's anomaly (Figure 47), which indicates a symmetrical distribution of gravity lows on either side of the St. David's syncline, suggesting folding of a bed. Thickening of the salt due to flowing or folding may have occurred in the areas of the gravity lows. A slight asymmetry in the northwest-southeast profiles through the St. Fintan's and the Robinsons anomalies may also reflect a bedded aspect of these deposits. The anomalies were interpreted using the available data of depth to the top of the salt following the method of Telford et al. (1976).

The anomalies of -2.6 to -2.7 mgal at the St. Fintan's and Robinsons River deposits suggest a larger mass of salt than the geological and drill-hole information indicates. Thus, either the total thickness of salt was not penetrated in the drilling or the glacial overburden thickens over the deposits and increases the intensity of the negative anomaly. A thicker deposit could have resulted from repetition of the salt unit by folding or faulting, and requires the existence of deeper layers of salt than the drill holes penetrated.

The Fischells Brook deposit is more than 390 m thick, three times as thick as the other two deposits. This suggests that either salt movement occurred to form a thick plug or an area southeast of the Flat Bay anticline was actively subsiding at the time of deposition, thus producing thick evaporite deposits. Evidence has already been presented (see Chapter 2, Codroy Group) suggesting that an actively subsiding depression controlled salt deposition during deposition of the Jeffrey's Village Member in the northern part of the subbasin and possibly also in the Codroy Road Formation. Flow structures, varying dips, steeply dipping crystal lineations and foliations, numerous slip surfaces and brecciation in the deposit, however, also indicate thickening of the deposit by flow. The Bouguer gravity data for the deposit (Hooker Chemical Corporation, 1971) suggests a cylindrical body with maximum radius of about 1000 m and a thickness of 1200 m. This size of deposit would contain about 7,000 million tonnes of salt. The eastern margin is limited by a presumed fault, east of which occur at least 900 m of Barachois sediments (Amax Exploration, 1976). The salt plug possibly formed following the faulting and folding, with the salt flowing toward the low pressure area on the upthrown side of the fault. The volume of salt possible in this deposit is 3500 million cubic metres. This suggests that, if the Fischells Brook salt plug formed from a bed 150 m thick, flowage would have had to occur from an area of about 1.5 km radius around the deposit.

Summary

Thick deposits of salt, some of good quality, are present in the Bay St. George subbasin. All the drilled deposits contain potash salts as well as halite. The drilling has been limited to the centres of the gravity anomalies and the flanks have not been explored. The thickest potash deposits in Carboniferous salt deposits of New Brunswick occur on the flanks. This suggests that further drilling of the flanks of the anomalies is required to assess their true potential. There is also a need to establish firmly whether the salts are restricted to the lower Jeffrey's Village Member of the Robinsons River Formation or whether they also occur in the Codroy Road Formation.

Part 3 - Coal

Coal was discovered in rocks of the Barachois Group in the Bay St. George subbasin in 1839 by J.B. Jukes, and in 1866 by Alexander Murray. By 1900, the St. George's coalfield had been outlined and coal beds had also been found at two localities in the Codroy lowlands. The history of exploration has seen the optimism of early explorers (Howley, 1897, 1913; Baker, 1927) turn to pessimism in the 1930's (Bryan, 1938; Summers, 1948; Hayes, 1949), followed by renewed cautious interest in the 1980's.

Little evidence of the early exploration remains today except for rotten timbers, water- and earth-filled shafts, twisted rails and, here and there, some rusted machinery. Small heaps of decomposed coal occur near the workings but nowhere is a coal seam exposed. For this reason, the geology of the coal deposits in the subbasin is summarized from previous reports, including the pioneering work and the exploration efforts in the 1930's and 1940's.

General description

Howley (1897, 1913) suggested that thick seams of good grade coal existed, and that as many as seven main seams are present in the St. George's coalfield and two in the Codroy lowlands near South Branch. All of the coals occur in the Barachois Group and are dated as Westphalian A, equivalent to the Riversdalian coals in Nova Scotia (Hacquebard et al., 1961; Hacquebard, 1972). Utting (1966) suggested, on miospore evidence, that the coals of the Codroy Valley are slightly older than those of the St. George's coalfield.

The coals were graded as high volatile B bituminous coals (Hayes and Johnson, 1938; Hayes, 1949). Termed lower rank, the coals varied from 47% to 70% free carbon, 3% to 10% and rarely 24% ash and 1% to 4% but also up to 8% sulfur. The coal seams were originally described as 1.5 to 7 m thick by Howley (1897, 1913), but were subsequently shown to be composed of aggregate thicknesses of black shale, fireclay, good coal beds up to 60 cm thick, and layers of alternating thin coals and shale (Bryan, 1938; Hayes, 1949). The coals occur in structurally complex areas with folding and faulting producing steeply dipping beds and discontinuity of the seams. The folding and faulting made mapping of the seams difficult and indicated to later workers that the coal deposits were generally of poor economic potential (Bryan, 1938; Summers, 1948; Hayes, 1949).

Coal in the Codroy Valley

Coal is located along Campbells Brook near Tompkins and Coal Brook near South Branch (Howley, 1897). The Campbells Brook deposit is reported as "a thin, one-foot [30 cm] thick coal" associated with a unit of interbedded thin coals and shale with gray sandstones (Hayes and Johnson, 1938). It appears that the seam was lenticular in shape and highly shattered due to nearby faulting; although some coal was extracted, the seam was soon abandoned and is no longer accessible.

The Coal Brook prospect was explored quite intensively in the 1890's and Howley (1897) records the tremendous efforts expended in reaching these coal seams. The coals occur in a 75 m section of gray sandstones interbedded with gray shales and clays. A 1.5 to 7 m coal seam, the Jubilee seam, and the 60 cm thick Begonia seam (Hayes, 1949) were uncovered and led Howley to become optimistic about the area. In addition to these two seams, the sequence includes at least two thinner seams, a number of coal partings, and fireclays with impure coals. The coals were said to be clean, fairly free from pyrite, and of variable thickness, with the thicker coals divided by shale partings. Drift workings along the main seam indicated that sandstone pillars, part of the footwall sandstone, interrupted the coal abruptly in places. This suggested that the coal formed lenticular deposits intertonguing within a shale bed (Hayes and Johnson, 1938). The seam terminates against the Long Range Fault, where it is shaly, sheared and crushed.

Reserves of 95,000 to 195,000 tonnes of coal were estimated by MacLean (1946). A few hundred tonnes of coal were mined from the prospect by the Reid Company, who opened up several hundred metres of workings (Hayes, 1949).

The present mapping suggests that the coals lie in a fault-bounded wedge of strata between the northeasterly trending Long Range fault and a subparallel fault which separates the coal-bearing gray sandstone sequence from red conglomerates and sandstones of the Mollichignick Member.

St. George's coalfield

The coal area of Barachois Brook and Robinsons River has been called the St. George's coalfield (Hayes, 1949). Although several exploratory endeavors have attempted to unravel the complex structure and sedimentary sequence (Fletcher, 1874; Howley, 1897; Dowling, 1920; Baker, 1927; Bryan, 1938; Hayes and Johnson, 1938; Summers, 1948; Hayes, 1949), no clear definition of the size, shape or extent of the coal-bearing stratum is known to this day.

The coalfield occurs in a doubly plunging syncline that hinges between Robinsons River and its tributary, Northern Feeder. The coal appears to occur in the uppermost strata of the Barachois Group in an area from immediately south of Barachois Brook to north of Northern Feeder. A lower and an upper sequence of coals are separated by about 550 m of barren sandstones and shales. Drill logs (Hayes, 1949; Hayes and Johnson, 1938) indicate that at least seven different coal seams and partings occur. Of these, the three seams from the upper sequence, the Furlong (92 cm), Jukes (154 cm), and Cleary (90 cm), appear to contain the best coal prospects. The seams were known from exposures in the banks of Barachois Brook at the junction with Joe McKays Brook but are now covered by soil slumps and tree falls. The seams were exposed by trenching and drifting (Howley, 1913; Dowling, 1920; Bryan, 1938) and drilled on several occasions (Hayes, 1938; Summers, 1948; Hayes, 1949). Dowling (1920) estimated that they contain between 890,000 and 1.6 million tonnes, with between 500,000 and 960,000 tonnes recoverable.

The upper coal sequence consists of coal, shale and clay between hanging walls and footwalls of gray sandstone. They have been fully described by Bryan (1938).

The Furlong seam contains a consistent stratigraphy in two exposures (Bryan, 1938): sandstone overlain by 12 cm clay, 32 cm coal with a thin sandy shale layer, 45 cm shale which thins southwards, and an upper sandstone.

The Jukes seam was observed in three showings and includes three sedimentary divisions. A basal coal, 42 to 54 cm thick, occurs with sandstone lenses which appear to disappear southward; this is overlain by a middle 75 cm sequence of 2 to 5 cm thick coals that alternate with equal thicknesses of shale; the upper part consists of 35 cm of clays and thin coal partings, overlain by the hanging wall sandstone. The lowest coal layer in the middle sequence thickens southward into a 20 cm coal bed. In general, coal layers of this middle section, which are lenticular and irregular in northern exposures of the seams, are more persistent in the south.

The Cleary seam contains a basal 3 m fireclay overlain by 60 cm of coal and shale. Four coal layers, decreasing in thickness upward from 27 to 3 cm, are separated by shales from 0.75 to 2.5 cm thick. A 30 cm shale layer caps the uppermost coal below the hanging wall sandstone.

Bryan (1938) found evidence of shearing and a number of slip faults in the three seams, and noted the resultant deterioration of coal quality. He also pointed out that the ash and pyrite contents of the coals appeared variable.

The lower coal sequence occurs along Barachois Brook. It includes the Tom Diamond coal seam 2 km upstream from the upper coal seams, and the Murray seam 3.5 km downstream from them. These two seams are believed to be equivalent (Dowling, 1920). The Tom Diamond seam consists of only 1 to 2 cm of coal in 60 cm of shales. Bryan (1938) considered the Murray bed to be a lenticular deposit. It locally thickens up to 120 cm by drag-folding adjacent to a fault, and rapidly wedges out into dark shale away from the fault. Both seams were affected by faulting.

The northernmost showings in the coalfield are also probably in the lower coal sequence. The Howlev coal occurs on Robinsons River and the Shears coal (Howley, 1913) occurs on Northern Feeder. Neither Hayes (1949) nor Bryan (1938) found any coal exposures along Northern Feeder, although both reported coal as float in the stream bed. Howley (1913) reported the Shears coal to be 35 cm thick and of good quality. The Howley coal is disturbed by a nearby fault and, although described as 125 cm thick by Howley (1913), it contains two coals 10 cm and 33 cm thick separated by a shale bed (Bryan, 1958). The Shears coal contains 35 cm of coal of good quality (Howley, 1913).

In summary, coals of the St. George's coalfield occur at two stratigraphic levels in the Barachois Group. Sedimentological evidence suggests that the lower coals are lenticular and grade laterally into shales whereas the upper coals may be true seams. It is possible that the lower coal sequence was deposited at the same time as the coals of the Codroy lowlands, which are dated by miospores as older than the coals of the upper sequence (Utting, 1966).

The past drilling failed to prove the continuity of the coal seams, although it must be emphasized that core recovery was poor, the coals usually being destroyed when penetrated. Mapping has shown that the upper coal beds occur on the west limb and at the south closure of the Barachois synclinorium; there is no definite evidence of their presence on the east limb. High angle reverse faults (Bryan, 1938) complicate the internal structure of the synclinorium. The present mapping has not elucidated the controlling structures nor the extent of the coals. Clearly, more detailed mapping and structural analysis aided by appropriately located drill holes are necessary to confirm the continuity of the coals and the presence of a mineable coalfield.

Part 4 - Uranium and Associated Minerals

Evidence for uranium mineralization throughout the Bay St. George subbasin, particularly in areas underlain by the upper formations of the Codroy Group, was indicated by airborne radiometric (Richardson et al., 1975), scintillometer (Knight, 1976), and geochemical (Davenport and Butler, 1976a and b) surveys. Low grade mineralization was discovered in sediments of the Codroy Group in this survey and occurs in a zone along the Grand Codroy River from South Branch to Doyles (Knight, 1976) in the southwestern part of the basin. Minor copper mineralization, mostly malachite, has been noted widely at uranium showings and in rock units that host these showings.

The uranium is hosted by sediments of the Mollichignick and Overfall Brook Members of the Robinsons River Formation, Codroy Group.

Description of Uraniferous Rocks

Mollichignick Member

Uranium values from scintillometer showings with 6x background values in the Mollichignick Member vary from 11 to

107 g/t (Knight, 1976; Dunsmore, 1977b). Assays of rock chips indicate a positive correlation of uranium and copper values, with copper values up to 3000 g/t (Knight, 1976). Copper occurs visibly as malachite disseminations and stains but many samples with positive uranium and copper assays have no visible mineralization.

Radioactivity is associated with two types of fining-upward clastic sequences. In the first type, the host rocks are fine grained, flaggy, micaceous, carbonaceous sandstones (lithofacies C, Robinsons River Formation) 1 to 2 m thick that are interbedded with red siltstones and minor gray mudstones. The showings were located in this type of host rock in the west bank of the Grand Codroy River, 1.5 to 2.5 km west of South Branch. The basal contact of the sandstone beds is often irregular, and high radioactivity (6x background) occurs discontinuously along it, particularly where the contact is underlain by gray mudstones. These zones are only a few centimetres thick and perhaps 10 to 20 cm wide. High radioactivity also occurs in thin, arch-shaped zones and in diffuse areas up to 10 cm wide within the sandstones. The arches are rooted at the basal scour of a bed and may extend upward into a bed in an arc which can be 1 to 3 m in diameter.

In the second type, radioactivity occurs in association with the coarse basal part of classic fining-upward, meandering, fluvial sequences (lithofacies D, Robinsons River Formation; cf. Allen, 1965a). These showings occur at the mouth of Stephens Brook near South Branch and 1.5 and 4 km upstream from Codroy Provincial Park along the banks of the Grand Codroy River. The highest counts (4x to 6x background) were recorded where pebbles, mud clasts and carbonaceous plant fossils form lenses in the basal parts of sandstone beds. The sandstones are in many cases porous and are cross-bedded, with erosional basal scours into underlying red siltstones. Malachite is locally visible near plant fossils or mud chips. This type of mineralization is similar to the Pugwash-Tatamagouche-type sandstone deposits (Dunsmore, 1977a and b) identified in Carboniferous strata of the Maritimes. However, the first type cannot be fitted neatly into this or the other types delineated by Dunsmore (1977b).

Overfall Brook Member

Minor uranium mineralization also occurs in basal strata of the Overfall Brook Member. It occurs in 50 to 400 cm thick sequences of gray mudstones and sandstones (lithofacies H and J, Robinsons River Formation) that are interspersed in red arkosic and muddy grits and sandstones that characterize the member. Carbonaceous plant trash and mud clasts are common in the gray beds, which also contain local mudflow deposits. Several of these gray sequences in the lower part of the member contain some sandstone and mudstone beds, mostly 10 to 25 cm thick, that emit radiation 6x to 7x background. Dunsmore (1977b), checking the original showing at the junction of Overfall Brook and Grand Codroy River (Knight, 1976; Brown and Knight, 1976), found 323 g/t of uranium and rated this prospect as one of the most significant in the Newfoundland Carboniferous. The style of sediment and mineral association does not appear to resemble any other found in the Maritimes (Dunsmore, 1977b).

Copper mineralization

Copper minerals such as chalcocite and malachite that occur in associations and settings similar to the uranium mineralization described above are discussed in this section. The mineralization occurs in fluvial sediments of the Searston Formation of the Barachois Group in both the Codroy Valley and St. George's coalfield. Fletcher (1874) described the presence of disseminated chalcopyrite in sandstones on Barachois Brook, 2.4 km upstream from the coal showings at Joe McKays Brook. Disseminated chalcopyrite and pyrite over an interval of 45 cm occur in association with plant trash in the Amax drill core near Fischells Brook (Amax Exploration, 1976). The mineralization is hosted by rocks of the Barachois Group and occurs at a 575 m depth in the hole. These showings are associated with coarse basal beds rich in plant trash and pebble debris in the lower parts of fining-upward cycles. Anomalous copper values were also found in stream sediments from Crabbes River, over the lower beds of the St. George's coalfield (McArthur et al., 1975a). No uranium was detected in these sediments but vanadium was recorded by Rose (1969) in sandstones of the Codroy Group on Crabbes River. Vanadium is commonly associated with sandstone-type uranium deposits.

Prospective Uranium Areas, Based on Uranium Geochemical Surveys

Uranium anomalies have been outlined within the subbasin by geochemical lake- and stream-sediment surveys (Davenport and Butler, 1976a and b; McArthur et al., 1975a). In an attempt to eliminate anomalies due to detrital uranium-bearing minerals such as zircon, allanite and sphene, only coincident copper-uranium anomalies are here considered to reflect possible areas of uranium mineralization.

Copper-uranium anomalies occur over Carboniferous rocks adjacent to the older crystalline basement on the east side of the Codroy Valley and in the vicinity of Fischells Brook and Mt. Howley. High uranium values in stream sediments have been recorded over a wide area of gneisses and schists of the Long Range Mountains east of the Codroy Valley (Taylor, 1970). These rocks may be the direct source of the anomalies in the streams on the east side of the subbasin. Near Mt. Howley, copper-uranium anomalies occur along Clam Brook, which drains Otter and Brow Ponds. Minor disseminated malachite occurs in arkosic sediments of the Brow Pond lentil in this area (N. Mercer, personal communication, 1980). A brief scintillometer survey of part of the Brow Pond area revealed no radioactive anomalies.

Within the Bay St. George subbasin, away from any apparent crystalline source, high uranium and copper stream- and lake-sediment samples were recorded along Plaster Brook in the Flat Bay area (McArthur et al., 1975a). These anomalous values occur over or near the gypsum deposits of the Codroy Road Formation of the Flat Bay anticline. Other uranium anomalies occur in the vicinity of Butter and French Brooks, and these are also close to the gypsum zones in the Codroy Road Formation. The airborne radiometric anomaly at Robinsons (Richardson et al., 1975) appears to occur over the Codroy Road Formation.

Uranium Potential in the Bay St. George Subbasin

Sedimentary rocks deposited upon alluvial fans, alluvial plains, and in lacustrine and marginal marine environments are known to contain important uranium mineralization elsewhere (Gabelman, 1971). Fluvial deposits in the Carboniferous of the Maritimes have been shown to host significant uranium mineralization (Brummer, 1958; Prest et al., 1969; Little and Durham, 1971; Dunsmore, 1977a and b). However, the best showings in the Maritimes are generally in younger rocks than those found in the Bay St. George subbasin.

In the Bay St. George subbasin, the following sequences are suggested to have good potential.

(a) Mollichignick Member: it contains known uranium showings and extensive fluvial and alluvial fan sediments as well as several lacustrine units. These rocks lie adjacent to the present basin margin, where a uranium source is located in the Long Range gneisses (Taylor, 1970). Carbonaceous material is present in many lithofacies.

(b) Overfall Brook Member: it consists of alluvial fan sediments with some fine basinal clastics that host uranium occurrences. It is adjacent to a basement uranium source. Carbonaceous sedimentary rocks are also present.

(c) Arkoses of the St. George's Bay area where they lie adjacent to basement: these include rocks of the Codroy Group and the Anguille Group and the Brow Pond Lentil. Transitions from alluvial fan deposits to fine, basinal sedimentary rocks may be important.

(d) Searston Formation and Barachois Group in Codroy Valley and St. George's Bay lowlands: these rock units contain fining-upward fluvial cycles with abundant plant trash. They contain copper and pyrite showings at the base of channel sandstone deposits. Sandstones are commonly reduced. Dark gray mudstones with plant trash, and thin coals alternating with shales and siltstones occur in the Barachois Group. There is abundant evidence that pore fluids migrated through the sandstones. This includes calcified sandstones and bleaching.

(e) Highlands Member: Red sandstones of the member contain vanadium-centred reduction spots and some areas of bleaching. Fining-upward fluviatile sequences are common. Some sandstones are yellow in color.

(f) Spout Falls Formation (Anguille Group) predominantly contains redbeds deposited by braided streams. Bleaching and secondary reduction is common. The formation is capped by Ship Cove Formation (Windsor A limestone) below which sediments are often in a reduced state. Charbonneau and Ford (1978) and Kirkham (1978) described anomalous uranium values in a stratigraphically similar, reduced zone of the Horton Group below the Windsor A (Macumber) limestone of Nova Scotia as well as in the limestones themselves.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The Bay St. George subbasin is a Devonian-Carboniferous, dominantly nonmarine successor basin the formation of which was controlled by movements upon several northeasterly trending faults of the Hercynian Cabot Fault system. Sedimentation spanned a time interval of perhaps 45 to 60 million years starting in Late Devonian (Famennian) and continuing through to Middle Pennsylvanian time (Westphalian C). Three groups have been recognized in the subbasin; namely, from base to top, the Anguille Group of lacustrine, fluvial-deltaic and fluviatile strata, the Codroy Group dominated by fluviatile redbeds but including marine siliciclastics, carbonates and evaporites, and the Barachois Group of fluvial and coal-bearing strata.

The important conclusions are outlined below.

Creation and Early Evolution of the Bay St. George Subbasin

The Bay St. George subbasin began as a 'pull-apart' basin (Crowell, 1974a and b) controlled by right-lateral strike-slip faulting on the northeasterly trending Long Range and associated faults. The subbasin probably formed where a bend, or more probably, a splay fault developed off the Long Range fault southwest of the Steel Mountain anorthosite. The splay fault trended almost due west along the northern edge of the subbasin and then turned southwestwards to form its northwestern margin. The southwestern margin probably coincided with a north trending basement arch (Howie and Barss, 1975a) that lies offshore from Cape Anguille. The Long Range fault formed the southeastern margin of the subbasin for most of its geologic history. Basin pull-apart began probably as early as late Middle or early Late Devonian time and continued at least until early or middle Viséan time. During this time interval, the basin extended southwestwards a distance of approximately 130 km.

Structural evolution of the subbasin during the deposition of the Anguille Group and basal Codroy Group

During the deposition of the Anguille Group, the subbasin was a narrow northeasterly trending graben, 30 km wide, lying between uplands located to the northwest (the Humber Arm Allochthon highlands), the northeast (above and northeast of the Steel Mountain anorthosite), and the southeast (the paleo-Long Range highlands). This narrow subbasin was primarily influenced by its border faults, but faults such as the Snakes Bight fault within the subbasin were also active. Three thick basin-fill sequences occur. The first of Famennian age (Kennels Brook Formation) and the second of Tournaisian (to early Viséan ?) age (Snakes Bight through Spout Falls Formations) make up the Anguille Group. The third is of middle Viséan age and comprises the basal Codroy Group. These three sequences are arranged geographically within the subbasin from southwest to northeast respectively, suggesting that the locus of subsidence and sedimentation shifted northeastward as the pull-apart basin evolved.

During this basin extension, most detritus was derived from mountains situated northeast and southeast of the subbasin. The provenance areas are recognized as probably similar to those of the Lower Paleozoic metamorphic and volcanic-plutonic terranes that now lie northeast of the subbasin and east of the Long Range fault in central Newfoundland. To the northwest, the Humber Arm Allochthon highlands appear to have first provided detritus to the subbasin in early Tournaisian time during the deposition of the younger formations of the Anguille Group.

Distribution and relative ages of conglomerates in the Anguille Group that were derived from the Humber Arm

Allochthon highlands suggest that the highlands originally lay 95 to 130 km southwest of their present position. They were displaced northeastwards during the deposition of the Anguille Group and occupied their present geographic position during the early history of the Codroy Group. Movement possibly averaged between 0.5 to 0.8 cm per year. During deposition of upper Anguille - basal Codroy rocks, the highlands may have been displaced as much as 60 km in as few as 5 million years, giving average annual displacements of 1.2 cm.

During the deposition of the basal Codroy Group, irregular distribution of small subsiding, evaporite-bearing troughs and of positive arches is believed to reflect the response of the subbasin to the last phases of active wrench movements.

Structural evolution of the subbasin during the deposition of the Codroy and Barachois Group

There is no direct evidence for wrench fault movements during deposition of rocks younger in age than those of the basal Codroy Group. The stratigraphic record of the time interval represented by post-basal Codroy Group and Barachois Group strata indicates the subbasin broadened to include the region now beneath St. George's Bay, a width of between 45 and 60 km. Beneath the bay, a 5 to 6 km thick sequence of Codroy and Barachois Group sedimentary rocks suggests this part of the subbasin became a major sediment depository as basement probably subsided in the area. Subsidence occurred principally along northeasterly trending faults that underlie the bay (Spector, 1969; Golden Eagle Developments, 1975).

Detritus in alluvium of the two groups suggests that the source lay principally in pre-Carboniferous terranes directly southeast of the Long Range fault in the paleo-Long Range highlands. Pebble distribution in these groups indicates that Silurian-Devonian intrusive and volcanic rocks of central Newfoundland had a greater geographic distribution to the southwest than they do at present. Minor detritus was shed from the Humber Arm allochthon highlands locally into the northern end of the subbasin during the deposition of the Codroy Group. Some detritus was also derived from uplands composed principally of Fleur de Lys type metamorphic rocks that lay to the northeast of the subbasin. In the Codroy lowlands, upper Codroy Group sedimentary rocks are 4 km thick adjacent to the Long Range fault, which suggests that the subbasin was influenced by block faulting and the vertical uplift of the paleo-Long Range highlands. This uplift continued throughout the interval represented by the Barachois Group.

History of Sedimentation

Anguille Group

Sedimentation in the Anguille Group can be divided into two phases. The early phase consisted of redbeds of the Kennels Brook Formation that were deposited probably during Late Devonian time. These redbeds may have been part of a broad molasse blanket that had existed from Early Devonian time. Most likely, however, they represent the first deposits to accumulate in the pull-apart basin.

The second phase of sedimentation is of Early Carboniferous age (Hortonian). This phase records the formation and infill within the subbasin of a relatively deep, meromictic or oligomictic lake that formed under semiarid climatic conditions. Lake-bottom muds, lacustrine turbidites and large sandy deltas possibly associated with sublacustrine fans filled the lake (Snakes Bight Formation). As the lake was filled, it became shallow and was restricted to the southwest end of the subbasin, and delta, fan-delta, shallow lakeshore environments and an extensive delta plain developed (Friars Cove Formation). The rocks of this formation change northwards and upwards into sandy redbeds of dominantly ephemeral and braided stream origin (Spout Falls Formation). The Fischells conglomerate member of the Spout Falls Formation was deposited locally in the northern part of the subbasin as coarse gravel fans near the end of this phase of Anguille Group sedimentation.

Codroy Group

Sedimentation in the Codroy Group began with marine transgression and deposition of limestones of the Ship Cove Formation. The marked change from nonmarine redbeds to marine carbonates at this contact suggests that a hiatus separates the Anguille and Codroy Groups. However, field relationships at the contact are ambiguous and paleontological information is lacking so that the hiatus cannot be confirmed. Deposition of the Ship Cove Formation was followed by accumulation of marine carbonates and evaporites and of marine and nonmarine siliciclastic rocks of the Codroy Road Formation and the lower part of the Robinsons River Formation (Windsor subzone A and early subzone B). Nonmarine sedimentation then gradually gained in importance upwards through the group as the upper part of the Robinsons River Formation and the Woody Cape Formation (late Windsor subzone B to subzone E) were deposited.

The limestones and shales of the Ship Cove Formation were deposited on a quiet, intertidal algal flat that extended northward into a subtidal setting. The landward margin lay to the southeast. The Codroy Road Formation formed in and near an elongate arm of the Windsor sea located in the vicinity of St. George's Bay. The subbasin was flooded by near normal marine waters which yielded fossiliferous limestones and biohermal buildups. Shoaling caused evaporitic conditions to develop as regression proceeded. For example, gypsum was deposited widely in a stable sabkha flat in the north and in shallow lagoons and associated sabkhas in the south. Fine redbeds encroached northwards across a coastal plain in the southeast of the subbasin. Cyclicity of lithofacies suggests a number of transgressive - regressive cycles occurred. No evidence of deep basinal evaporitic conditions has been observed. Salt may have accumulated east of the Flat Bay 'divide' during deposition of the Codroy Road Formation.

The Robinsons River Formation is subdivided into four members and one informally named unit, the Brow Pond lentil. The members comprise a large variety of nonmarine and marine lithofacies. The Jeffrey's Village Member consists of two sequences divided at the Fischells limestone. The lower sequence (early Windsor subzone B) includes fine siliciclastics and some of the major salt deposits of the subbasin, which are postulated to have accumulated in several rapidly subsiding sinks. The salinas were shallow and surrounded by evaporitic mudflats spotted with muddy hypersaline ponds and fine muddy alluvial fans. Periodically, the salinas were flooded by fresh water and at such times rivers deposited deltas of fine sand into the salinas.

The upper sequence of the Jeffrey's Village Member probably formed a sedimentary blanket of more uniform thickness consisting of redbeds, marine carbonates and minor evaporites. Nonmarine environments in the redbeds of the upper part of the Jeffrey's Village Member included playa flats, alluvial flood plains, ephemeral, braided and meandering streams, and coarse and muddy alluvial fans. Towards the top of the member, it includes a major coarsening-upward sequence that culminated in the deposition of the overlying Highlands Member (late Windsor subzone B and subzone C). The redbeds of the Highlands Member were deposited by high sinuosity rivers that flowed west-southwestwards along the axis of the subbasin.

Clean arkosic sandstones of the Brow Pond lentil were deposited as a major alluvial fan that built out into the northeastern corner of the subbasin. Other alluvial fans were present in the northern and along the southeastern sides of the subbasin during the deposition of the upper Jeffrey's Village Member and the Highlands Member.

The marine deposits of the upper Jeffrey's Village Member occur mostly towards the base of the sequence. They include carbonates with some evaporites and siliciclastics that were deposited in shallow lagoons, algal banks and flats, oolitic and sandy shoals and beaches, and shallow shelf environments. The character of the carbonate units changes upwards within the Jeffrey's Village Member so that units displaying characteristics of open marine shelf are superseded by those dominated by algal banks, oolite shoals and, rarely, lagoonal sulfate evaporites. Transgressions were slow and widespread, and both short- and long-lived marine conditions occurred. Marine sequences consist of shoaling-upward cycles and many of the marine carbonates developed calcretes and other features of vadose freshwater diagenesis. Dolomitization occurred in some units. The cyclic carbonate-redbed sequences of the member are typical of transgression and offlap sequences of the Windsor Group (Schenk, 1969).

Seawater entered the subbasin from the north and southwest during the deposition of the marine beds of the basal Codroy Group. The Variscan Ocean, east of Newfoundland (Jansa et al., 1978; Jansa and Mamet, 1979) is suggested here to have been connected to the subbasin by a seaway that likely lay along the western side of the Great Northern Peninsula. Near normal ocean waters flooded the subbasin along this seaway. When the seaway was cut off, hypersaline waters spilled into the subbasin from the larger Maritimes Basin, thus leading to salt deposition.

The Mollichignick Member (Windsor subzone D and E?) consists of two basin-fill sequences. The first is made up of lacustrine rocks, sheetflood-dominated alluvium and muddy, pebbly, semiarid alluvial fan deposits that are arranged in several coarsening-upward megasequences. The second consists of playa flat and floodplain and meandering river channel deposits overlain by coarser braided stream deposits. These facies were capped by a humid alluvial fan sequence, the Overfall Brook Member.

The Windsor sea flooded the southwestern part of the subbasin late in the depositional history of the Codroy Group (Windsor subzones D and E). Thin, fluvially dominated deltas were deposited in the Woody Cape Formation. Delta lithofacies include offshore mudstones and siltstones, delta front sheet sandstones, delta channel sandstones and several lithofacies typical of delta plain subenvironments. The Windsor Sea also inundated the flood plain of the middle Mollichignick Member on several occasions.

During deposition of the Codroy Group, the subbasin was fed dominantly by short-headed, steep-gradient streams. However, evidence from the lower Codroy Group, especially in the salt-bearing strata of the Jeffrey's Village Member, strongly suggests that larger perennial rivers entered the subbasin in the northeast. Such rivers probably originated far within central Newfoundland.

Two paleoflow regimes occurred in the subbasin during deposition of the Codroy Group, and included northwestward paleoflow from the basin margin towards basin axis and southwestward paleoflow along the axis of the subbasin. Arrangement of sedimentary depositional environments from the margin to the axis of the subbasin in relation to the northwestward paleoflow included (a) alluvial fan to sheetflood and sandy braided stream to lake environments, (b) alluvial fan to braided stream - ephemeral stream to distal flood plain or playa flat to marine environments and (c) alluvial fan to playa flat to marine environments. Lithofacies order associated with axial paleoflow was mostly from alluvial fan to braided or low sinuosity streams to high sinuosity streams to marine.

Climate during deposition of the Codroy Group was generally semiarid. More arid conditions during deposition of the lower Codroy Group led to widespread precipitation of evaporites when influx of fine terrigenous material was low. Caliche, locally well developed at specific stratigraphic intervals such as the middle of the Jeffrey's Village Member, the middle of the Highlands Member and the middle of the Mollichignick Member, support continuing semiarid climatic conditions for much of the time represented by the Codroy Group. Increased precipitation is suggested by the absence of mature and old age caliches in the youngest strata of the Codroy Group and by humid alluvial fan deposits of the Overfall Brook Member.

Variable calcrete (caliche) development suggests that sedimentation rates and tectonic stability in the subbasin varied greatly during deposition of the Codroy Group. Coarsening-upward megasequences and basin-fill sequences in nonmarine strata and cyclicity of marine and nonmarine beds also suggest tectonically controlled sedimentation. This tectonic activity was sited primarily upon the border faults of the subbasin, producing basin subsidence and source uplift.

Barachois Group

The Barachois Group is subdivided into two sequences. The lower sequence consisting of the Searston Formation is composed of fining-upward fluviatile sequences typical of meandering river channel and floodplain deposits. The rivers flowed westwards to northwestwards from the paleo-Long Range highlands. An upper coal-bearing sequence was deposited in generally similar fluvial conditions but included backswamp lakes and marshes, adjacent to river channels, in which coals accumulated.

The climate during deposition of the Barachois Group began as semiarid but was less arid than the climate during the deposition of the Codroy Group. Immature pedogenic profiles together with the thickness of the fluvial succession in the Searston Formation suggest that seasonal precipitation was higher in the subbasin or source area. A more humid climate is also indicated by the younger coal-bearing strata of the Barachois Group.

Deformation

The subbasin was deformed during the Variscan orogeny. The oblique orientation of fold axes relative to the major northeasterly trending faults in and bordering the subbasin, northeasterly trending synthetic faults and northwesterly trending antithetic faults suggest that the Carboniferous strata of the subbasin were deformed primarily by right-lateral strike-slip fault movements. Wrench movements occurred during the late Pennsylvanian on the Long Range fault and other northeasterly trending faults such as the Snakes Bight fault. From provenance studies of upper Codroy Group and Barachois Group strata adjacent to the Long Range fault, it appears that only minor lateral displacements upon this border fault could have occurred. Later displacements were dominantly vertical.

Interpretation of right-lateral strike-slip movements throughout the geologic history of the subbasin is contrary to recent plate tectonic models, based upon paleomagnetic studies that suggest sinistral wrench faulting should have affected the area. The geologic history of the subbasin does, however, support the recent model suggested for the evolution of the Maritimes Basin by Bradley (1982), who attributed its development to wrench tectonics of a dextral fault system.

Mineralization

Small occurrences of chalcopyrite, chalcocite, galena, sphalerite and barite occur in the centre of the subbasin in rocks of the Snakes Bight and Ship Cove Formations. Most of the showings are in veins and minor faults. Minor sandstone-hosted zinc and lead sulfides also occur at the top of the Anguille Group in the Spout Falls Formation.

Important barite and celestite prospects occur along the northern margin of the subbasin in carbonate strata of the Ship Cove Formation where they unconformably overlie Paleozoic rocks of the Port au Port Peninsula. Galena is present in the same area. The mineralization is of diagenetic, early postdepositional origin.

High quality gypsum and salt deposits occur in the lower part of the Codroy Group in the northern part of the subbasin. Potash salts are known and the potential is considered good for the discovery of significant potash deposits in several of the salt structures outlined by gravity surveys. Salt deposits appear to have accumulated in the lower part of Windsor subzone B, although the Fischells Brook salt deposit may also include subzone A salt.

Areas of anomalous radioactivity with visible malachite occur in lacustrine and fluviatile siliciclastic rocks of the Mollichignick and Overfall Brook Members of the Robinsons River Formation in the Codroy lowlands. Malachite is also present in fluviatile rocks of the Barachois Group.

Coal seams occur in the Barachois Group. Potential for recoverable deposits is poor, however, because of the local structural complexity of the coal measures.

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REFERENCES CITED

Aitken, J.D.
1967: Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta. Journal of Sedimentary Petrology, Volume 37, pages 1163-1178.

Allen, J.R.L.
1963: The classification of cross-stratified units, with notes on their origin. Sedimentology, Volume 2, pages 93-114.

1964a: Studies in fluviatile sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh Basin. Sedimentology, Volume 3, pages 163-198.

1964b: Primary current lineation in the Lower Old Red Sandstone (Devonian), Anglo-Welsh Basin. Sedimentology, Volume 3, pages 98-108.

1965a: A review of the origin and characteristics of recent alluvial sediments. Sedimentology, Volume 5, pages 89-191.

1965b: Fining upwards cycles in alluvial successions. Geological Journal, Volume 4, pages 229-246.

1970a: Studies in fluviatile sedimentation: a comparison of fining-upwards cyclothems with special reference to coarse-member composition and interpretation. Journal of Sedimentary Petrology, Volume 40, pages 298-323.

1970b: Physical Processes of Sedimentation. London: Allen & Unwin, 248 pages.

1974: Studies in fluviatile sedimentation: implications of pedogenic carbonate units. Lower Old Red Sandstone. Anglo-Welsh outcrop. Geological Journal, Volume 9, pages 181-208.

Allen, J.R.L., and Friend, P.F.
1968: Deposition of the Catskill facies, Appalachian region: with notes on some other Old Red Sandstone basins. *In* Late Paleozoic and Mesozoic Continental Sedimentation, Northeastern North America. *Edited by* G. De Vries *Klein*. Geological Society of America, Special Paper 106, pages 21-74.

Allen, J.R.L., and Williams, B.P.J.
1979: Interfluvial drainage on Siluro-Devonian alluvial plains in Wales and the Welsh Borders. Journal of the Geological Society of London, Volume 136, pages 361-366.

Alling, H.L.
1938: Plutonic perthites. Journal of Geology, Volume 46, page 142.

Amax Exploration Inc.
1976: Drilling report for salt, St. George's Bay, west Newfoundland. Unpublished report. Open File 12B/7 (208).

American Association of Petroleum Geologists
1970: Code of stratigraphic nomenclature. American Commission on Stratigraphic Nomenclature. 22 pages.

American Geological Institute
1972: Glossary of Geology.

Arthaud, F., and Matte, P.
1977: Late Palaeozoic strike-slip faulting in southern Europe and northern Africa. Result of a right-lateral shear zone between the Appalachians and the Urals. Bulletin of the Geological Society of America, Volume 88, pages 1305-1320.

Asserretto, R.L.A.M., and Kendall C.G.St.C.
1977: Nature, origin and classifi-

cation of peritidal tepee structures and related breccias. Sedimentology, Volume 24, pages 153-210.

Badiozamani, K.
1973: The Dorag dolomitization model-application to the Middle Ordovician of Wisconsin. Journal of Sedimentary Petrology, Volume 43, pages 965-984.

Baird, D.M.
1949: Salt possibilities of southwestern Newfoundland. Newfoundland Geological Survey, unpublished report, Open File Nfld 417, 137 pages

1951: Gypsum deposits of southwestern Newfoundland. Canadian Institute of Mining and Metallurgy, Volume 54, pages 85-94.

1954: The magnetite and gypsum deposits of the Sheep Brook-Lookout Brook area. *In* Contributions to the Economic Geology of Western Newfoundland. Geological Survey of Canada, Bulletin, Volume 27, pages 20-41.

1959: Development of gypsum deposits in southern Newfoundland. Bulletin of the Canadian Institute of Mining and Metallurgy, Volume 52, pages 495-502.

Baird, D.M., and Cote, P.R.
1964: Lower Carboniferous sedimentary rocks in southwestern Newfoundland and their relations to similar strata in western Cape Breton Island. Bulletin of the Canadian Institute of Mining and Metallurgy, Volume 57, pages 509-520.

Baker, H.A.
1927: The St. George's Coalfield, Newfoundland. Paper presented to a meeting of the 2nd (Triennial) Empire Mining and Metallurgical Congress, St. John's, Open File 12B (5).

Baker, V.R.
1977: Stream-channel response to floods with examples from central Texas. Bulletin of the Geological Society of America, Volume 88, pages 1057-1071.

Ballard, R.D. and Uchupi, E.
1972: Triassic rift structure in the Gulf of Maine. Bulletin of the American Association of Petroleum Geologists, Volume 59, pages 1041-1072.

Banerjee, I.
1977: Experimental study on the effect of deceleration on the vertical sequence of sedimentary structures in silty sediments. Journal of Sedimentary Petrology, Volume 47, pages 771-783.

Barwiss, J.H.
1976: Internal geometry of Kiawah Island beach ridges. *In* Terrigenous Clastic Depositional Environments. *Edited by* M. O. Hayes and T. W. Kana. Technical Report No. 11-CRD, Coastal Research Division, University of S. Carolina, pages II-128 to II-142.

Basan, P.B.
1978: Introduction. *In* Trace Fossil Concepts. *Edited by* P.B. Basan. SEPM Short Course No. 5, Oklahoma City, pages 1-10.

Bathurst, R.G.C.
1975: Carbonate Sediments and Their Diagenesis. Amsterdam: Elsevier, 2nd edition, 658 pages.

Baxter, S., and von Bitter, P.H.
1979: Conodont succession in Mississippian strata of Canada. Abstract, 9th International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois, page 14.

Beadle, L.C.
1974: The Inland Waters of Tropical Africa. London: Longman. 365 pages.

Beales, F.W., and Oldershaw, A.E.
1969: Evaporite-solution brecciation and Devonian carbonate reservoir porosity in western Canada. Bulletin of the American Association of Petroleum Ceologists, Volume 53, pages 503-512.

Beard, D.C. and Weyl, P.K.
1973: Influence of texture on porosity and permeability of unconsolidated sand. Bulletin of the American Association of Petroleum Geologists, Volume 57, pages 349-369.

Bell, W.A.
1929: Horton-Windsor district, Nova Scotia. Geological Survey of Canada, Memoir 155, 268 pages.

1948: Early Carboniferous strata of St. Georges Bay area, Newfoundland. Geological Survey of Canada, Bulletin 10, 45 pages.

1960: Mississippian Horton Group of type Windsor-Horton District, Nova Scotia. Geological Survey of Canada, Memoir 314. 112 pages.

Belt, E.S.
1965: Stratigraphy and paleogeography of Mabou Group and related Middle Carboniferous facies, Nova Scotia, Canada. Bulletin of the Geological Society of America, Number 76, pages 777-809.

1966: Stratigraphy and palaeogeography of Middle Carboniferorus facies, Newfoundland, Canada. Unpublished report, National Science Foundation, GP-2858, 25 pages.

1968a: Carboniferous continental sedimentation, Atlantic Provinces, Canada. *In* Late Paleozoic and Mesozoic Continental Sedimentation, Northeastern North America. *Edited by* G. de V. Klein. Geological Society of America, Special Paper 106, pages 127-176.

1968b: Post-Acadian rifts and related facies, eastern Canada. *In* Studies of Appalachian Geology: Northern and Maritime. *Edited by* E-An Zen, W.S. White, J.B. Hadley, and J.S. Thompson, Jr. New York: Wiley Interscience, pages 95-113.

1969: Newfoundland Carboniferous stratigraphy and its relation to the Maritimes and Ireland. *In* Symposium on Stratigraphy and Structure Bearing on Continental Drift in the North American Ocean, Gander Meeting, 1967. *Edited by* M. Kay. American Association of Petroleum Geologists, Memoir 12, pages 734-753.

Belt, E.S., Freshney, E.C., and Read, W.A.
1967: Sedimentology of Carboniferous cementstone facies, British Isles and eastern Canada. Journal of Geology, Volume 75, pages 711-721.

Belt, E.S., Gillis, J.W., and Webb, G.W.
1969: Investigation of the strike-slip possibilities on the Long Range Fault, S.W. Newfoundland. Unpublished report, Open File Nfld 683.

Benson, D.G.
1974: Geology of the Antigonish Highlands, Nova Scotia. Geological Survey of Canada, Memoir 376, 92 pages.

Bernoulli, D., and Wagner, C.
1971: Subaerial diagenesis and fossil caliche deposits in the Calcare Massiccio Formation (Lower Jurassic, Central Apennines, Italy). Neues Jahrbuch Fuer Geologie and Palaontologie, Abhandlungen 138, pages 145-149.

Binney, W.P.
1975: Copper occurrences in Lower Carboniferous sedimentary rocks of

the Maritime Provinces. Geological Survey of Canada, Open File 281, 156 pages.

Blanchard, J.E.
1953: Report of gravity meter survey - St. Fintans area, Newfoundland. Nova Scotia Research Foundation, unpublished report, Open File 12B/2 (57).

Blatt, H. and Christie, J.M.
1963: Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies in sedimentary rocks. Journal of Sedimentary Petrology, Volume 33, pages 559-579.

Blatt, H., Middleton, G.V., and Murray, R.C.
1972: Origin of Sedimentary Rocks. New Jersey: Prentice-Hall, 634 pages.

Blissenbach, E.
1954: Geology of alluvial fans in semi-arid regions. Bulletin of the Geological Society of America, Volume 65, pages 175-189.

Bluck, B.J.
1967: Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area: a study in the significance of bedding. Scottish Journal of Geology, Volume 3, pages 139-167.

1978: Sedimentation in a late orogenic basin: the Old Red Sandstone of the Midland Valley of Scotland. *In* Crustal Evolution of Northwest Britain and Adjacent Regions. *Edited by* D.R. Bowes, and B.E. Leake. Geological Journal, Special Issue Number 10, pages 249-278.

1980: Evolution of strike-slip fault-controlled basin, Old Red Sandstone, Scotland. *In* Sedimentation in Oblique Slip Mobile Zones. *Edited by* P.F. Ballance, and H.G. Reading. International Association of Sedimentologists, Special Publication Number 4, Blackwell Scientific Publications, pages 63-78.

Boehner, R.C.
1981a: Stratigraphy and depositional history of marine evaporites in the Lower Carboniferous Windsor Group, Shubenacadie and Musquodoboit structural basins, Nova Scotia, Canada. Paper presented at the 9th International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois, 1979, 28 pages.

1981b: Preliminary report on the geology and mineral deposits of the Loch Lomond Basin, Cape Breton Island. Nova Scotia Department of Mines, Report 81-1.

Boothroyd J.C.
1972: Coarse-grained sedimentation on a braided outwash fan, northeast Gulf of Alaska. Coastal Research Division. University of South Carolina, C.R.D. Technical Report Number 6, 127 pages.

Boothroyd, J.C. and Ashley, G.M.
1975: Process, bar morphology and sedimentary structures on braided outwash fans, north-eastern Gulf of Alaska. *In* Glaciofluvial and Glaciolacustrine Sedimentation. *Edited by* A.V. Jopling, and B.C. McDonald. Society of Economic Paleontologists and Mineralogists, Special Publication 23, pages 193-222.

Bouma, A.H.
1962: Sedimentology of some flysch deposits: a graphic approach to facies interpretation. Amsterdam: Elsevier, 168 pages.

Boyle, R.W.
1963: The geology, geochemistry and origin of the barite, manganese and lead-zinc-copper-silver deposits of

the Walton-Cheverie area, Nova Scotia. Geological Survey of Canada, Bulletin 166, 181 pages.

Bradley, D.A.
1962: Gisborne Lake and Terrenceville map areas, Newfoundland. Geological Survey of Canada, Memoir 321, 56 pages.

Bradley, D.C.
1982: Subsidence in Late Paleozoic basins in the Northern Appalachians. Tectonics, Volume 1, pages 107-123.

Braunagel, L.H., and Stanely, K.O.
1977: Origin of variegated red beds in the Cathedral Bluffs Tongue of the Wasatch Formation (Eocene) Wyoming. Journal of Sedimentary Petrology, Volume 47, pages 1201-1219.

Brookes, I.A.
1969: Late glacial marine overlap in western Newfoundland. Canadian Journal of Earth Sciences, Volume 6, page 1397.

1977a: Geomorphology and Quaternary geology of Codroy lowlands and adjacent plateaus, southwest Newfoundland. Canadian Journal of Earth Sciences, Volume 14, pages 2101-2120.

1977b: Radiocarbon age of Robinson's Head Moraine, west Newfoundland, and its significance for post-glacial sea level changes. Canadian Journal of Earth Sciences, Volume 14, pages 2121-2126.

Brown, P.A.
1976: Ophiolites in southwestern Newfoundland. Nature, Volume 264, pages 712-715.

1977: Geology of the Port aux Basques map area (110/11) Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 77-2, 11 pages.

Brown, P.A., and Knight, I.
1976: Codroy map sheet, preliminary geological map. Mineral Development Division, Newfoundland Department of Mines and Energy.

Bruckner, W.D.
1978: Exhumed pre-Carboniferous landforms in west Newfoundland. Abstract, Eastern Canada Palaeontology and Biostratigraphy Seminar, Corner Brook, Newfoundland.

Brummer, J.J.
1958: Supergene copper-uranium deposits in northern Nova Scotia. Economic Geology, Volume 53, pages 309-324.

Bryan, A.M.
1938: St. George's coalfield, Newfoundland. Geological Survey of Newfoundland, Information Circular Number 5.

Brynhi, I.
1978: Flood deposits in the Hornelen Basin, west Norway (Old Red Sandstone). Norsk Geologisk Tidsskrift, Volume 58, pages 273-300.

Bull, W.B.
1964: Geomorphology on segmented alluvial fans in Western Fresno County, California. United States Geological Survey, Professional Paper 352-E, pages 89-129.

1972: Recognition of alluvial-fan deposits in the stratigraphic record. *In* Recognition of Ancient Sedimentary Environments. *Edited by* K.J. Rigby and W.K. Hamblin. Society of Economic Paleontologists and Mineralogists, Special Publication 16, pages 68-83.

Burst, J.F.
1965: Subaqueously formed shrinkage cracks in clay. Journal of Sedimentary Petrology, Volume 35, pages 348-353.

Bush, P.R.
1973: Some aspects of the diagenetic history of the sabkha in Abu Dhabi Persian Gulf. *In* The Persian Gulf. *Edited by* B.H. Purser. Berlin: Springer-Verlag, pages 395-407.

Butler, G.P.
1969: Modern evaporative deposition and geochemistry of coexisting brines, the sabkha, Trucial Coast, Arabian Gulf. Journal of Sedimentary Petrology, Volume 39, pages 70-89.

Calcutt, M.
1973: The stratigraphy and sedimentology of the Cinq Isles Formation, Fortune Bay, Newfoundland. Unpublished M. Sc. Thesis, Memorial University of Newfoundland.

Cameron, K.L., and Blatt, H.
1971: Durabilities of sand-size schist and 'volcanic' rock fragments during fluvial transport, Elk Creek, Black Hills, South Dakota. Journal of Sedimentary Petrology, Volume 41, pages 565-576.

Cant, D.J.
1978: Development of facies model for sandy braided river sedimentation. Comparison of the South Saskatchewan River and the Battery Point Formation. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 627-639.

Cant, D.J., and Walker, R.G.
1976: Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Quebec. Canadian Journal of Earth Sciences, Volume 13, pages 102-119.

1978: Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. Sedimentology, volume 25, pages 625-648.

Carroll, R. L., Belt, E.S., Dineley, D.L., Baird, D.M., and McGregor, D.C.
1972: Vertebrate Paleontology of Eastern Canada. Guidebook for Excursion A.59, 24th International Geological Congress, Montreal.

Chamberlain, C.K.
1978: Recognition of trace fossils in cores. *In* Trace Fossil Concepts. *Edited by* P.B. Basan. SEPM short course Number 5, Oklahoma City, pages 119-166.

Charbonneau, B.W. and Ford, K.L.
1978: Uranium mineralization at the base of the Windsor Group, South Maitland, Nova Scotia. Current Research, Part A, Geological Survey of Canada, Paper 78-1A, pages 419-425.

Choquette, P.W., and Pray, L.C.
1970: Geologic nomenclature and classification of porosity in sedimentary carbonates. Bulletin, American Association of Petroleum Geologists, Volume 54, pages 207-250.

Chorlton, L.
1979: La Poile River map area, Newfoundland. *In* Report of Activities for 1978. *Edited by* R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, pages 45-53.

Chorlton, L., and Dingwell, D.
1981: Grandys Lake, Newfoundland. *In* Current Research. *Edited by* C.F. O'Driscoll and R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 81-1, pages 57-69.

Chorlton, L., and Knight, I.
In press: Geology of the Grandys Lake map sheet. Mineral Development Division, Newfoundland Department of Mines and Energy, Report.

Cleary, W.J., and Connelly, J.R.
1971: Distribution and genesis of quartz in a piedmont - coastal plain environment. Bulletin of the Geological Society of America, Volume 82, pages 2755-2766.

Clifton, H.E.
1973: Pebble segregation and bed lenticularity in wave-worked versus alluvial gravel. Sedimentology, Volume 20, pages 173-187.

Cline, L.M.
1970: Sedimentary features of late Palaeozoic flysch, Ouachita Mountains. *In* Flysch Sedimentalogy in North America. *Edited by* J. Lajoie. Geological Association of Canada, Special Paper Number 7, pages 85-102.

Coleman, J.M.
1969: Brahmaputra River; channel process and sedimentation. Sedimentary Geology, Volume 30, pages 129-239.

1976: Deltas: Processes of Deposition and Models for Exploration. Continuing Education Publication Company, Inc., 102 pages.

Coleman, J.M., and Gagliano, S.M.
1965: Sedimentary structures, Mississippi delta plain. *In* Primary Sedimentary Structures and Their Hydrodynamic Interpretation - A symposium. *Edited by* G.V. Middleton. Society of Economic Paleontologists and Mineralogists, Special Publication 12, pages 133-148.

Coleman, J.M., Gagliano, S.M., and Webb, J.E.
1964: Minor sedimentary structures in a prograding distributary. Marine Geology, Volume 1, pages 240-258.

Collinson, J.D.
1970a: Bedforms of the Tana River, Norway. Geografiska Annaler Series, 52-A, pages 31-56.

1970b: Deep channels, massive beds and turbidity current genesis in the Central Pennine Basin. Proceedings of the Yorkshire Geological Society, Volume 37, pages 495-519.

1972: The Rode Ø Conglomerate of Inner Scoresby Sund and the Carboniferous (?) and Permian rocks west of the Schuchert Fjord. Meddelelser om Groenland, Bd. 192, Nr. 6, pages 1-48.

1978a: Alluvial sediments. *In* Sedimentary Environment and Facies. *Edited by* H.G. Reading. Blackwell Scientific Publications, pages 15-60.

1978b: Vertical sequence and sand body shape in alluvial sequences. *In* Fluvial Sedimentology. *Edited by* A.D. Maill. Canadian Society of Petroleum Geology, Memoir 5. pages 577-586.

Conaghan, P.J., and Jones, J.G.
1975: The Hawkesbury sandstone and the Brahmaputra: a depositional model for continental sheet sandstones. Journal of the Geological Society of Australia, Volume 22, pages 275-283.

Connelly, J.R.
1965: The occurrence of polycrystallinity and undulatory extinction in quartz in sandstones. Journal of Sedimentary Petrology, Volume 35, pages 116-135.

Cooke, R.U., and Warren, A.
1973: Geomorphology in Deserts. London: Longman, pages 275-283.

Cooper, J.R.
1954: La Poile-Cinq Cerf map-area, Newfoundland, Geological Survey of Canada, Memoir 276, 62 pages.

Corbett, K.D.
1973: Open-cast slump sheets and their relationship to sandstone beds in an Upper Cambrian flysch sequence, Tasmania. Journal of Sedimentary Petrology, Volume 43, pages 147-159.

Cote, P.R.
1964: Lower Carboniferous sedimentary rocks of the Horton

Group in parts of Cape Breton Island and their relationship to similiar strata of the Anguille Group in southwestern Newfoundland. Unpublished Ph.D. Thesis, University of Ottawa.

Cotter, E.
1978: The evolution of fluvial style, with special reference to the central Appalachian Paleozoic. *In* Fluvial sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 361-384.

Crowell, G.D.
1971: The Kaiser celestite operation at Loch Lomond. Canadian Mining and Metallurgical Bulletin, Volume 74, pages 48-52.

Crowell, J.C.
1957: Origin of pebbly mudstones. Bulletin, Geological Society of America, Volume 68, pages 993-1009.

1974a: Sedimentation along the San Andreas Fault, California. *In* Modern and Ancient Geosynclinal Sedimentation. *Edited by* R.H. Dott, Jr., and R.H. Shaver. Society of Economic Paleontologists and Mineralologists, Special Publication 19, pages 292-303.

1974b: Origin of late Cenozoic basins in southern California. *In* Tectonics and Sedimentation. *Edited by* W.R. Dickinson. Society of Economic Paleontologists and Mineralologists, Special Publication 22, pages 190-204.

1979: The San Andreas fault system through time. Journal of the Geological Society of London, Volume 136, pages 293-302.

Currie, K.L.
1977: A note on post-Mississippian thrust faulting in northwestern Cape Breton Island. Canadian Journal of Earth Sciences, Volume 14, pages 2937-2941.

Davenport, P.H., and Butler, A.J.
1976a: Uranium distribution in lake sediments in western Newfoundland and the Avalon and Burlington Peninsulas. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Nfld. 904.

1976b: Uranium distribution in stream sediments in Codroy - Bay St. George, western Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Nfld. 906.

Davies, J.L.
1964: A morphogenic approach to world shorelines. Zeitschrift fuer Geomorphologie, Volume 8, 27-42.

Davis, R.A.
1978: Coastal Sedimentary Environments. New York: Springer-Verlag, 420 pages.

Deer, W.A., Howie, R.A., and Zussman, J.
1974: An Introduction to the Rock-Forming Minerals. London: Longman, 528 pages.

Deffreyes, K.S., Lucia, F.J. and Weyl, P.K.
1965: Dolomitisation of recent and Plio-Pleistocene sediments by marine evaporite waters on Bonaire, Netherlands Antilles. *In* Dolomitisation and Limestone Diagenesis, A symposium. *Edited by* L.C. Pray, and R.C. Murray. Society of Economic Paleontologists and Mineralogists, Special Publication 13, pages 71-88.

Degens, E.T., von Herzen, R.P., and Wong, H.K.
1971: Lake Tanganyika: water chemistry, sediments, geological structure. Naturwissenschaften, Volume 58, pages 229-241.

Dewey, J.F.
1974: The geology of the southern termination of the Caledonides. *In* The Ocean Basins and Margins, The

North Atlantic. *Edited by* A.E.M. Nairn and F.G. Stehli. New York: Plenum, pages 205-231.

Dewey, J.F., and Kidd, W.S.F.
1974: Continental collisions in the Appalachian-Caledonian orogenic belt: variations related to complete and incomplete suturing. Geology, Volume 2, pages 543-546.

Dillon, W.P., and Sougy, J.M.A.
1974: Geology of west Africa and Canary and Cape Verde Islands. *In* The Ocean Basins and Margins, The North Atlantic. *Edited by* A.E.M. Nairn and F.G. Stehli. New York: Plenum, pages 315-390.

Dineley, D.L., and Williams, B.P.J.
1968: Sedimentation and paleoecology of the Devonian Escuminac Formation and related strata, Escuminac Bay, Quebec. *In* Late Paleozoic and Mesozoic Continental Sedimentation, Northeastern North America. *Edited by* G. de Vries Klein. Geological Society of America, Special Publication 106, pages 241-264.

Dix, G.R.
1981: The Codroy Group (Upper Mississippian) on the Port au Port Peninsula, Western Newfoundland: stratigraphy, palaeontology, sedimentology and diagenesis. Abstract, unpublished M.Sc. thesis, Memorial University of Newfoundland.

Doeglas, D.J.
1962: The structure of sedimentary deposits of braided rivers. Sedimentology, Volume 1, pages 167-190.

Donaldson, A.C., Martin, R.H., and Kanes, W.H.
1970: Holocene Guadalupe delta of Texas Gulf Coast. *In* Deltaic Sedimentation Modern and Ancient. *Edited by* J.P. Morgan, and R.H. Shaver. Society of Economic Paleontologists and Mineralogists, Special Publication 15, pages 107-137.

Donovan, D.T., and Jones, E.J.W.
1979: Causes of world wide changes in sea level. Journal of the Geological Society of London, Volume 136, pages 187-192.

Donovan, R.N.
1975: Devonian lacustrine limestones at the margin of the Orcadian Basin, Scotland. Journal of the Geological Society of London, Volume 131, pages 489-510.

Donovan, R.N., and Foster, R.J.
1972: Subaqueous shrinkage cracks from the Caithness Flagstone Series (Middle Devonian) of northeast Scotland. Journal of Sedimentary Petrology, Volume 42, pages 309-317.

Dorf, E., and Cooper, J.R.
1943: Early Devonian plants from Newfoundland. Journal of Paleontology, Volume 17, pages 264-270.

Dott, R.H., Jr.
1963: Dynamics of subaqueous gravity depositional process. Bulletin of the American Association of Petroleum Geologists, Volume 47, pages 104-128.

Douglas, C. and Hsu E.
1976: Mineral occurrence tables, Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Nfld. 888.

Dowling, D.B.
1920: St. Georges coalfield, Newfoundland. Geological Survey of Newfoundland, unpublished report, Open File 12B (3).

Dunbar, C.O., and Rodgers, J.
1957: Principles of Stratigraphy. New York: Wiley & Sons, 356 pages.

Dunham, R.J.
1962: Classification of carbonate rocks according to depositional texture. *In* Classification of

Carbonate Rocks. *Edited by* W.E. Ham. American Association of Petroleum Geologists, Memoir 1, pages 108-121.

Dunsmore, H.E.
1977a: A new genetic model for uranium-copper mineralization, Permo-Carboniferous basin, northern Nova Scotia. *In* Report of Activities, Part B. Geological Survey of Canada, Paper 77-1B, p. 247-253.

1977b: Uranium resources of the Permo-Carboniferous basin, Atlantic Canada. *In* Report of Activities, Part B. Geological Survey of Canada, Paper 77-1B, pages 341-348.

Dzulynski, S., and Walton, E.K.
1965: Sedimentary Features of Flysch and Greywackes. Amsterdam: Elsevier, 274 pages.

Eckstein, Y.
1970: Physicochemical limnology and geology of a meromictic pond on the Red Sea shore. Limnology and Oceanography, volume 15, pages 363-372.

Elliott, T.
1974a: Abandonment facies of high-constructive lobate deltas, with an example from the Yoredale Series. Proceedings of the Geological Association, Volume 85, pages 359-365.

1974b: Interdistributary bay sequences and their genesis. Sedimentology, Volume 21, pages 611-622.

1975: The sedimentary history of a delta lobe from a Yoredale (Carboniferous) cyclothem. Proceedings of the Yorkshire Geological Society, Volume 40, pages 505-536.

1976a: Upper Carboniferous sedimentary cycles produced by river-dominated, elongate deltas. Journal of the Geological Society of London, Volume 132, pages 199-208.

1976b: The morphology, magnitude and regime of a Carboniferous fluvial-distributary channel. Journal of Sedimentary Petrology, Volume 46, pages 70-76.

1978a: Deltas. *In* Sedimentary Environments and Facies. *Edited by* H.G. Reading. Blackwell Scientific Publications, pages 97-142.

1978b: Clastic shorelines. *In* Sedimentary Environments and Facies. *Edited by* H.G. Reading. Blackwell Scientific Publications, pages 143-177.

Enos, P.
1969: Anatomy of a flysch. Journal of Sedimentary Petrology, Volume 39, pages 680-723.

Eugster, H.P., and Hardie, L.A.
1975: Sedimentation in an ancient playa-lake complex. The Wilkins Peak Member of the Green River Formation of Wyoming. Bulletin of the Geological Society of America, Volume 86, pages 319-334.

Evans, G.
1965: Intertidal flat sediments and their environments of deposition in the Wash. Quarterly Journal of the Geological Society of London, Volume 121, pages 209-245.

1975: Intertidal flat deposits of the Wash, Western margin of the North Sea. *In* Tidal Deposits. A Casebok of Recent Examples and Fossil Counterparts. *Edited by* R.N. Ginsberg. New York: Springer - Verlag, pages 13-20.

Evans, G., Schmidt, V., Bush, P., and Nelson, H.
1969: Stratigraphy and geologic history of the sabkha, Abu Dhabi, Persian Gulf. Sedimentology, Volume 12, pages 145-159.

Evans, R.
1970: Evaporites in the Mississippian of the Maritime Province of

Canada. 6th International Geological Congress on Carboniferous and Geology. Comptes Rendu, Volume 11, pages 725-735.

Eynon, G., and Walker, R.G.
1974: Facies relationships in Pleistocene outwash gravels, southern Ontario: a model for bar growth in braided rivers. Sedimentology, Volume 21, pages 43-70.

Fannin, N.G.T.
1969: Stromatolites from the Middle Old Red Sandstone of Western Orkney. Geological Magazine, Volume 106, pages 77-88.

Fisk, H.N., McFarlan, E. Jr., Kolb, C.R. and Wilbert, L.J. Jr.
1954: Sedimentary framework of the modern Mississippi delta. Journal of Sedimentary Petrology, Volume 24, pages 76-99.

Fleming, J.M.
1974: Salt exploration in Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, unpublished report, Open File 12B (177), 4 pages.

Fleming, J.M., and McArthur, J.G.
1976: Industrial minerals in Newfoundland and Labrador. Paper presented at 2nd Industrial Minerals International Congress, Munich, Germany, Open File Nfld 916.

Fletcher, H.R.
1874: Report on the coal property of Phillip Cleary, St. Georges Bay, Newfoundland. Memorandum relating to the Bay St. George coalfield owned by the estate of the late Hon. P. Cleary, St. John's, Open File 12B (1).

Flintkote Company of Canada
1972: Diamond drilling for gypsum in 1971 in the Fischell's River area, confidential unpublished report.

Flores, R.M.
1972: Delta front-delta plain facies of the Pennysylvannian Haymond Formation, northeastern Marathon Basin, Texas. Bulletin of the Geological Society of America, Volume 83, pages 3515-3424.

Folk, R.L.
1962: Spectral subdivisions of limestone types. *In* Classification of Carbonate Rocks. *Edited by* W. E. Ham. American Association of Petroleum Geologists, Memoir 1, pages 62-84.

1968: Petrology of Sedimentary Rocks. Austin, Texas: Hemphill, 170 pages.

Fong, C.C.K.
1974: Geological mapping - St. George's Bay Carboniferous area. *In* Report of Activities for 1973. *Edited by* W.R. Smyth. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 74-1, pages 66-69.

1976a: Geological mapping, northern half of the St. George's Bay Carboniferous Basin. *In* Report of Activities for 1975. *Edited by* B.A. Greene. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 76-1, pages 2-9.

1976b: Geology map Flat Bay - Main Gut, 12B/7. Mineral Development Division, Newfoundland Department of Mines and Energy, Map 774.

Fong, C.C.K., and Douglas, C.
1975: Geological mapping - northern part of the St. George's Bay Carboniferous basin. *In* Report of Activities for 1974. *Edited by* J.M. Fleming. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 75-1, pages 22-30.

Forgeron, S.
1977: The Kaiser celestite mining operation and mineral potential of the Loch Lomond Basin, Cape Breton, Nova Scotia. Nova Scotia Department of Mines, Open File Report 328.

Forstner, U., Muller, G., and Reineck, H.E.
1968: Sedimente and Sedimentgefuge des Rheindeltas in Bodensee. Neues Jahrbuch Fuer Mineralogie. Abhandlungen 109, pages 33-62.

Fraser, G.S., and Hester, N.C.
1977: Sediments and sedimentary structures of a beach ridge complex, southwestern shore of Lake Michigan. Journal of Sedimentary Petrology, Volume 47, pages 1187-1200.

Frey, R.W., and Howard, J.D.
1970: Comparison of Upper Cretaceous ichnofaunas from siliceous sandstones and chalk, western interior region, U.S.A. *In* Trace Fossils. *Edited by* T.P. Crimes and J.C. Harper. Geological Journal, Special Issue 3, pages 141-166.

Freytot, P.
1973: Petrography and palaeoenvironment of continental carbonate deposits with particular reference to the Upper Cretaceous and Lower Eocene Languedoc (southern France). Sedimentary Geology, Volume 10, pages 25- 60.

Friedman, G.M., and Radke, B.
1979: Evidence for sabkha overprint and conditions of intermittent emergence in Cambro-Ordovician carbonates of northeast North America and Queensland, Australia. Northeastern Geology, Volume 1, pages 18-42.

Friedman, G.M., Amiel, A.J., and Schneidermann, N.
1974: Submarine cementation in reefs: example from the Red Sea. Journal of Sedimentary Petrology, Volume 44, pages 816-825.

Friedman, G.M., Amiel A.J., Braun, M., and Miller, D.S.
1973: Generation of carbonate particles and laminites in algal mats - an example from sea-marginal hypersaline pool, Gulf of Aqaba, Red Sea. Bulletin of the American Association of Petroleum Geologists, Volume 57, pages 541-557.

Friend, P.F.
1966: Clay fractions and colors of some Devonian red beds in the Catskill Mountains. Journal of the Geological Society of London, Volume 122, pages 273-292.

1978: Distinctive features of some ancient river systems. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists Memoir 5, pages 531-542.

Frostick, L.E. and Reid, I.
1977: The origin of horizontal laminae in ephemeral stream channel fill. Sedimentology, Volume 24, pages 1-9.

Gabelman, J.W.
1971: Sedimentology and uranium prospecting. Sedimentary Geology, Volume 6, pages 145-186.

Galloway, W.E.
1975: Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. *In* Deltas, Models for Exploration. *Edited by* M.L. Broussard. Houston Geological Society, Houston, pages 87-98.

Garrett, P.
1970: Phanerozoic stromatolites: Non-competitive ecologic restriction by grazing and burrowing animals. Science, Volume 169, pages 171-173.

Gebelein, C.D.
1969: Distribution, morphology, and accretion rates of Recent subtidal

algal stromatolites, Bermuda. Journal of Sedimentary Petrology, Volume 34, pages 49-69.

1976: The effects of the physical, chemical and biological evolution of the earth. *In* Stromatolites. *Edited by* M.R. Walter. Developments in Sedimentology, 20, Amsterdam: Elsevier, pages 499-515.

Geldsetzer, H.H.J.
1977: The Windsor Group of Cape Breton Island, Nova Scotia. Geological Survey of Canada, Paper 77-1A, pages 425-428.

1978: The Windsor Group in Atlantic Canada - an update: Geological Survey of Canada Paper 78-1C, pages 43-48.

1979: Depositional development of the late Visean, Windsor Group in Atlantic Canada. Abstract, 9th International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois, pages 63-69.

Geological Survey of Canada
1968: Aeromagnetic map 7050G, Stephenville (12/B), Newfoundland, 1 inch to 4 miles.

1971: Aeromagnetic map 7042G. Port aux Basques (110), Newfoundland, 1 inch to 4 miles.

Gersib, G.A. and McCabe, P.J.
1981: Continental coal-bearing sediments of the Port Hood Formation (Carboniferous), Cape Linzee, Nova Scotia, Canada. *In* Recent and Ancient Non-Marine Depositional Environments: Models for Exploration. *Edited by* F.G. Etheridge and R.M. Flores. Society of Economic Paleontologists and Mineralogists, Special Publication 31, pages 95-108.

Gile, L.M., Peterson, F.F., and Grossman, R.B.
1966: Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science, Volume 101, pages 347-360.

Giles, P.S.
1977: The Carboniferous basin study. Report of Activities 1976, Nova Scotia Department of Mines, Report 77-1, pages 115-123.

Gillis, J.W.
1972: Geology of the Port aux Basques map-area, Newfoundland. Geological Survey of Canada, Paper 71-42, 6 pages.

Glennie, K.W.
1970: Desert Sedimentary Environments. Developments in Sedimentology, 14, Amsterdam: Elsevier, 222 pages.

Globensky, Y.
1967: Middle and Upper Mississippian conodonts from the Windsor Group of the Atlantic Provinces of Canada. Journal of Paleontology, Volume 41, pages 432-448.

Golden Eagle Development Ltd.
1975: A.A. Lee Exploration Ltd. Seismic interpretation in the St. George's Bay area, Newfoundland. Unpublished report, Open File 12B (191).

Goudie, A.
1973: Duricrusts in Tropical and Subtropical Landscapes. Oxford: Clarendon Press, 174 pages.

Gould, H.R.
1951: Some quantitative aspects of Lake Mead turbidity currents. Society of Economic Paleontologists and Mineralogists, Special Publication 2, pages 34-52.

1960: Turbidity currents. *In* Comprehensive Survey of Sedimentation in Lake Mead. United States Geological Survey, Professional Paper 295, pages 201-207.

Gray, R.S.
1967: Petrography of the Upper Cenozoic non-marine sediments in the San Pedro Valley, Arizona. Journal of Sedimentary Petrology, Volume 36, pages 774-789.

Greene, B.A.
1975: Harbour Breton map area. *In* Report of Activities, 1974. *Edited by* B.A. Greene. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 75-1, pages 3-9.

Greene, B.A., and O'Driscoll, C.F.
1976: Gaultois map area. *In* Report of Activities for 1975. *Edited by* B.A. Greene. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 76-1, pages 56-63.

Greiner, H.R.
1962: Facies and sedimentary environments of Albert Shale, New Brunswick. Bulletin of the American Association of Petroleum Geologists, Volume 46, pages 219-234.

1974: The Albert Formation of New Brunswick: a Paleozoic lacustrine model. Geologische Rundschau, Volume 63, pages 1102-1113.

Gussow, W.C.
1953: Carboniferous stratigraphy and structural geology of New Brunswick, Canada. Bulletin of the American Association of Petroleum Geologists, Volume 37, pages 1713-1816.

Gustavson, T.C.
1974: Sedimentation on gravel outwash fans, Malaspina glacier, Foreland, Alaska. Journal of Sedimentary Petrology, Volume 44, pages 374-389.

Hacquebard, P.A.
1972: The Carboniferous of Eastern Canada. *In* 7th Congres International de Stratigraphie et de Geologie du Carbonifère, Krefeld. Comptes Rendus, Bd. 1., pages 69-90.

Hacquebard, P.A. and Donaldson, J.G.
1969: Carboniferous coal deposition associated with floodplain and limnic environments in Nova Scotia. *In* Environments of Coal Deposition. Geological Society of America, Special Paper 114, pages 143-191.

Hacquebard, P.A., Barss, M.A., and Davidson, J.R.
1961: Distribution and stratigraphic significance of small spore genera in the Upper Carboniferous of the Maritime Provinces of Canada. Comptes Rendus, 4th Congres International de Stratigraphie et de Geologie du Carbonifère, Heerlen, pages 237-245.

Hagan, G.M., and Logan, B.W.
1974a: Development of carbonate banks and hypersaline basins, Shark Bay, Western Australia. *In* Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Memoir 22, pages 61-139.

1974b: History of Hutchinson Embayment tidal flat, Shark Bay, Western Australia. *In* Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Memoir 22, pages 283-315.

Halley, R.B.
1977: Ooid fabric and fracture in the Great Salt Lake and the geologic record. Journal of Sedimentary Petrology, Volume 47, pages 1099-1120.

Hampton, M.A.
1972: The role of subaqueous debris flow in generating turbidity currents. Journal of Sedimentary Petrology, Volume 42, pages 775-793.

Handford, C.R., and Moore, C.H. Jr.
1976: Diagenetic implications of calcite pseudomorphs after halite from the Jaochim Dolomite (Middle

Ordovician), Arkansas. Journal of Sedimentary Petrology, Volume 46, pages 387-392.

Hantzschel, W.
1975: Trace fossils and problematica. *In* Treatise on Invertebrate Palaeontology. Part W. Miscellanea, Supplement 1. *Edited by* C. Teichert. Geological Society of America and University of Kansas Press, 269 pages.

Hardie, L.A., and Eugster, H.P.
1971: The depositional environment of marine evaporites: a case for shallow clastic accumulation. Sedimentology, Volume 16, pages 187-220.

Hardie, L.A., Smoot, J.P., and Eugster, H.P.
1978: Saline lakes and their deposits: a sedimentological approach. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication 2, Blackwell Scientific Publications, pages 7-41.

Harms, J.C.
1969: Hydraulic significance of some sand ripples. Bulletin of the Geological Society of America, Volume 80, pages 363-396.

1975: Stratification produced by migrating bedforms. *In* Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences. Society of Economic Paleontologists and Mineralogists, Short Course 2, Dallas, pages 45-61.

Harms, J.C., and Fahnestock, R.K.
1965: Stratification, bed forms, and flow phenomena (with an example from the Rio Grande). *In* Primary Sedimentary Structures and their Hydrodynamic Interpretation. *Edited by* G.V. Middleton. Society of Economic Paleontologists and Mineralogists, Special Publication 12, pages 84-115.

Harms, J.C., MacKenzie D.B., and McCubbin, D.G.
1963: Stratification in modern sands of the Red River, Louisiana. Journal of Geology, Volume 71, pages 566-580.

Haworth, R.T.
1975a: Paleozoic continental collision in the northern Appalachians in light of gravity and magnetic data in the Gulf of St. Lawrence. *In* Geology of Offshore Eastern Canada, Volume 2. Regional Geology. *Edited by* W.J.M. van der Linden and J.A. Wade. Geological Survey of Canada, Paper 74-30, pages 1-10.

1975b: The development of Atlantic Canada as a result of continental collision - evidence from offshore gravity and magnetic data. *In* Canada's Continental Margins and Offshore Petroleum Exploration. *Edited by* C.J. Yorath, E.R. Parker, and D.J. Glass. Canadian Society of Petroleum Geologists, Memoir 4, pages 59-77.

Haworth, R.T., and Sanford, B.V.
1976: Paleozoic geology of southeast Gulf of St. Lawrence. Geological Survey of Canada, Paper 76-1A, pages 1-6.

Haworth, R.T., Poole, W.H., Grant, A.C. and Sanford, B.V.
1976: Marine geoscience survey northeast of Newfoundland. Geological Survey Canada, Paper 76-1A, pages 7-15.

Hayes, A.O.
1949: Coal possibilities of Newfoundland. Geological Survey of Newfoundland, Information Circular Number 6, 20 pages.

Hayes, A.O. and Field, J.G.
1948: Logs of coal drilling at South Branch. Newfoundland Department of Natural Resources, unpublished report, Open File 110 (18).

Hayes A.O., and Johnson, H.
1938: Geology of the Bay St. George Carboniferous Area. Geological Survey of Newfoundland, Bulletin Number 12, 62 pages.

Hayes, M.O., and Kana, T.W.
1976: Terrigenous clastic depositional environments - some modern examples. Technical Report 11-CRD, Coastal Research Division, University of South Carolina, pages I-32 to I-131, II-184.

Heckel, P.H.
1972: Recognition of ancient shallow marine environments. *In* Recognition of Ancient Sedimentary Environments. *Edited by* J.K. Rigby and W.K. Hamblin. Society of Economic Paleontologists and Mineralogists, Special Publication 16, pages 226-286.

Hein, F.J., and Walker, R.G.
1977: Bar evolution and development of stratification in the gravelly, braided, Kicking Horse River, British Columbia. Canadian Journal of Earth Sciences, Volume 14, pages 562-570.

Hesse, R. and Reading, H.G.
1978: Subaqueous clastic fissure eruptions and other examples of sedimentary transposition in the lacustrine Horton Bluff Formation (Mississippian), Nova Scotia, Canada. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication Number 2, Blackwell Scientific Publications, pages 239-257.

Heward, A.P.
1978a: Alluvial fan sequence and megasequence models: with examples from Westphalian D - Stephanian B coalfields, northern Spain. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 669-702.

1978b: Alluvial fan and lacustrine sediments from the Stephanian A and B (La Magdalena, Cinera-matellana and Sabero) coalfields, northern Spain. Sedimentology, Volume 25, pages 451-488.

Hibbard, J.,
In preparation: Geology of the Baie Verte Peninsula. Newfoundland Department of Mines and Energy, Memoir.

Higgs, K.
1975: Upper Devonian and Lower Carboniferous miospore assemblages from Hook Head, County Wexford, Ireland. Micropaleontology, Volume 21, pages 393-419.

Hobson, G.D., and Overton, A.
1973: Sedimentary refraction seismic surveys, Gulf of St. Lawrence. *In* Earth Science Symposium on Offshore Eastern Canada. *Edited by* P.J. Hood. Geological Survey of Canada, Paper 71-23, pages 325-336.

Hoffman, P.
1967: Algal stromatolites. Use in stratigraphic correlation and paleocurrent distribution. Science, Volume 157, pages 1043-1045.

1976: Stromatolite morphogenesis in Shark Bay, Western Australia. *In* Stromatolites. *Edited by* M.R. Walter. Developments in Sedimentology, 20, Amsterdam: Elsevier, pages 261-272.

Holmes, A.
1965: Principles of Physical Geology. 2nd Edition. London: Thomas Nelson and Sons, 1288 pages.

Holser, W.T.
1966: Diagenetic polyhalite in recent salt from Baja California. American Mineralogist, Volume 51, pages 99-109.

Hooke, R. Le. B.
1967: Processes on arid-region alluvial fans. Journal of Geology, Volume 75, pages 438-460.

Hooker Chemical Corporation
1968a: Summary report, detailed sample log, summary of potash mineralization, Salt Exploration Well No. 1. (Fischells), Newfoundland. Unpublished report, Open File 12B/7 (100).

1968b: Combined gravity meter and electrical resistivity survey, Fischell's Brook, St. Georges - Port au Port district. Unpublished report by Huntec Ltd, Open File 12B/7 (103).

1971: Report on gravity survey, Stephenville, and Codroy Regions, Nfld., and analysis of Fischells Brook Salt deposit. Unpublished report, Open File 12B (147).

1972: Robinsons - borehole log. Unpublished report, Open File 12B/7 (152).

1973: St. Fintan's salt deposit Unpublished Report, Open File 12B/2 (178).

Horne, J.C., Ferm, J.C., Caruccio, F.T., and Baganz, B.P.
1978: Depositional models in coal exploration and mine planning in Appalachian region. Bulletin of the American Association of Petroleum Geologists, Volume 62, pages 2379-2411.

Horodyski, R.J., Bloeser, B., and Haar, S.V.
1977: Laminated algal mats from a coastal lagoon, Laguna Mormona, Baja California, Mexico. Journal of Sedimentary Petrology, Volume 47, pages 680-696.

Horowitz, A.A., and Potter, P.E.
1971: Introductory Petrography of Fossils. New York: Springer-Verlag, 302 pages.

Houbolt, J.J.H.C., and Jonker, J.B.M.
1968: Recent sediments in the eastern part of the Lake of Geneva (Lac Leman). Geologie en Mijnbouw, Volume 47, pages 131-148.

Howard, J.D.
1972: Trace fossils as criteria for recognizing shorelines in the stratigraphic record. *In* Recognition of Ancient Sedimentary Environments. *Edited by* J.K. Rigby and W.K. Hamblin. Society of Economic Paleontologists and Mineralogists, Special Publication 16, pages 215-225.

Howie, R.D.
1979: Carboniferous evaporites in Atlantic Canada. Abstract, 9th International Congress on Carboniferous Stratigraphy and Geology, University of Illinois, Urbana, Illinois, pages 93-94.

Howie, R.D., and Barss, M.S.
1975a: Upper Paleozoic rocks of the Atlantic Provinces. Gulf of St. Lawrence and adjacent continental shelf. *In* Offshore Geology of Eastern Canada, Volume 2, - Regional Geology. *Edited by* W.J.M. van der Linden and J.A. Wade. Geological Survey of Canada, Paper 74-30, pages 35-50.

1975b: Paleogeography and sedimentation in the Upper Paleozoic, eastern Canada. *In* Canada's Continental Margins and Offshore

Petroleum Exploration. *Edited by* C.J. Yorath, E.R. Parker and D.J. Glass. Canadian Society of Petroleum Geologists, Memoir 4, p. 45-57.

Howie, R.D., and Cumming, L.M.
1963: Basement features of the Canadian Appalachians. Geological Survey of Canada, Bulletin 89, pages 1-18.

Howley, J.P.
1897: Report on coal deposits in the Codroy River Valley. Geological Survey of Newfoundland Report.

1913: Our coal areas. Lecture delivered before the Board of Trade, April 1, 1913, Open File Nfld. 17.

Hsu, K.J., and Kelts, K.
1978: Late Neogene sedimentation in the Black Sea. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication Number 2, Blackwell Scientific Publications, pages 127-144.

Hsu, K.J., and Schneider, J.
1973: Progress report on dolomitization - hydrology of Abu Dhabi sabkhas, Arabian Gulf. *In* The Persian Gulf. *Edited by* B.H. Purser. Berlin: Springer-Verlag, pages 409-422.

Hsu, K.J., and Siegenthaler, C.
1969: Preliminary experiments on hydrodynamic movement induced by evaporation and their bearing on the dolomite problem. Sedimentology Volume 12, pages 11-25.

Hubert, J.F.
1977: Paleosol caliche in the New Haven Arkose, Connecticut: record of semiaridity in Late Triassic - Early Jurassic time. Geology, Volume 5, pages 302-304.

Hubert, J.F., Reed, A.A., and Carey, P.J.
1976: Paleogeography of the East Berlin Formation, Newark Group, Connecticut Valley. American Journal of Science, Volume 276, pages 1183-1207.

Hubert, J.F., Reed, A.A., Dowdall, W.L., and Gilchrist, J.M.
1978: Guide to the redbeds of Central Connecticut 1978 Field Trip, Eastern Section of the Society of Economic Paleontologists and Mineralogists Guidebook, Contribution Number 32. Department of Geology and Geography, University of Masachusetts, Amherst, Massachusetts, 129 pages.

Hyde, R.S.
1978: Stratigraphic subdivision and mapping of the Lower Mississippian Anguille Group, Deer Lake - White Bay area, Newfoundland. *In* Report of Activities for 1977. *Edited by* R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 78-1, pages 116-123.

1979a: Geology of Carboniferous strata in portions of the Deer Lake basin, western Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Report 79-6.

1979b: Evolution of the Carboniferous Deer Lake Basin, west-central Newfoundland, Canada. Abstract, 9th International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois.

Hyde, R.S. and Ware, M.J.
1980: Geology of Carboniferous strata in the Cormack and Silver Mountain map areas. *In* Current Research. *Edited by* C.F. O'Driscoll and R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 80-1, pages 29-36.

1981: Geology of Carboniferous strata in the Deer Lake and Rainy Lake map areas, Newfoundland. *In*

Current Research. *Edited by* C.F. O'Driscoll and R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 81-1, pages 17-31.

Irving, E.
1977: Drift of the major continental blocks since the Devonian. Nature, Volume 270, pages 304-309.

1979: Paleopoles and paleolatitudes of North America and speculations about displaced terrains. Canadian Journal of Earth Sciences, Volume 16, pages 669-694.

Jackson R.G., II
1975: Velocity-bedform-texture patterns of meander bends in the Lower Wabash River of Illinois and Indiana. Bulletin of the Geological Society of America, Volume 86, pages 1511-1522.

1976: Depositional model of point bars in the Lower Wabash River. Journal of Sedimentary Petrology, Volume 46, pages 579-594.

1978: Preliminary evolution of lithofacies models for meandering alluvial streams. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 543-576.

James, N.P.
1972: Holocene and Pleistocene calcareous crust (caliche) profiles: criteria for subaerial exposure. Journal of Sedimentary Petrology, Volume 42, pages 817-836.

1979: Facies model 10, shallowing-upward sequences in carbonates. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada, Reprint Series 1, pages 109-119.

James, N.P. and Kobluk, D.R.
1978: Lower Cambrian patch reefs and associated sediments, southern Labrador, Canada. Sedimentology, Volume 25, pages 1-36.

James, N.P., Ginsburg, R.N., Marszalek, D.S., and Choquette, P.W.
1976: Facies and fabric specificity of early subsea cements in shallow Belize (British Honduras) reefs. Journal of Sedimentary Petrology, Volume 46, pages 523-544.

Jansa, L.F., and Mamet, B.L.
1979: Viséan offshore Eastern Canada: Paleogeographic and plate tectonic implications. Abstract, 9th International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois, page 99.

Jansa, L.F., and Wade, J.A.
1975: Geology of the continental margin off Nova Scotia and Newfoundland. *In* Offshore Geology of Eastern Canada, Volume 2 - Regional Geology. *Edited by* W.J.M. van der Linden and J.A. Wade. Geological Survey of Canada, Paper 74-30, page 51-105.

Jansa, L.F., Mamet, B.L., and Rouz, A.
1978: Visean limestones from the Newfoundland Shelf. Canadian Journal of Earth Sciences, Volume 15, pages 1422-1436.

Jayasinghe, N.R.
1979: Geology of the Noel Paul's Brook area (12A/9), Newfoundland. *In* Report of Activities for 1978. *Edited by* R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 79-1, pages 25-29.

Johnson, H.
1954: The strontium deposits of Port au Port Peninsula. *In* Contributions to the Economic Geology of Western Newfoundland. Geological Survey of Canada, Bulletin 27, pages 1-19.

Johnson, J.H.
1971: An introduction to the study of organic limestones. Quarterly Journal of the Colorado School of Mines, Volume 66, 185 pages.

Jopling, A.V., and Walker, R.G.
1968: Morphology and origin of ripple-drift cross-lamination, with examples from the Pleistocene of Massachusetts. Journal of Sedimentary Petrology, Volume 38, pages 971-984.

Jukes, J.B.
1843: General report of the Geological Survey of Newfoundland, John Murray, London.

Kanes, W.H.
1970: Facies and development of the Colorado River Delta in Texas. *In* Deltaic Sedimentation, Modern and Ancient. *Edited by* J.P. Morgan. Society of Economic Paleontologists and Mineralogists, Special Publication 15, pages 78-106.

Karcz, I.
1972: Sedimentary structures formed by flash floods in southern Israel. Sedimentary Geology, Volume 7, pages 161-182.

Kean, B.F.
1977: Geology of the Victoria Lake map area. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 77-4, 11 pages.

1978: Geology of the Star Lake sheet, east half, Newfoundland. *In* Report of Activities for 1977. *Edited by* R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 78-1, pages 129-134.

1979: Buchans map area (12A/15), Newfoundland. *In* Report of Activities for 1978. *Edited by* R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 79-1, pages 18-24.

In preparation: Geology of the King George IVth map area. Newfoundland Department of Mines and Energy, Preliminary Report.

Kean, B.F., and Jayasinghe, N.R.
1981: Geology of the King George IV map area (12A/14), Newfoundland. *In* Current Research. *Edited by* C.F. O'Driscoll and R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 81-1, pages 32-39.

Kelley, D.G.
1967a: Baddeck and Whycocomagh map areas, with emphasis on Mississippian stratigraphy of central Cape Breton Island, Nova Scotia. Geological Survey of Canada, Memoir 351, 65 pages.

1967b: Some aspects of Carboniferous stratigraphy and depositional history in the Atlantic Provinces. Geological Association of Canada, Special Paper 4, pages 213-228.

Kelley, D.G., and Mackasey, W.O.
1965: Basal Mississippian volcanic rocks in Cape Breton Island, Nova Scotia. Geological Survey of Canada, Paper 64-34, 10 pages.

Kelling, G., and George, G.T.
1971: Upper Carboniferous sedimentation in the Pembrokeshire coalfield. *In* Geological Excursion in South Wales and the Forest of Dean. *Edited by* D.A. Bassett and M.G. Bassett. Geological Association, South Wales Group, Cardiff, pages 240-259.

Kelts, K., and Briegel, U.
1971: Sediment slides and turbidity current models from Swiss Lakes. Abstract, VIII th International Sedimentological Congress, page 49.

Kendall, A.C.
1979a: Facies model 13, continental and supratidal (Sabkha) evaporites. *In* Facies models. *Edited by* R.G. Walker. Geoscience Canada Reprint Series 1, pages 145-157.

1979b: Facies Model 14, subaqueous evaporites. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada Reprint Series 1, pages 159-174.

Kendall, C.G. St.C., and Skipwith, P.A. d'E.
1968: Recent algal mats of a Persian Gulf lagoon. Journal of Sedimentary Petrology, Volume 38, pages 1040-1058.

1969: Holocene shallow water carbonate and evaporite sediments of Khor al Bazam, Abu Dhabi, southwest Persian Gulf. Bulletin of the American Association of Petroleum Geologists, Volume 53, pages 841-849.

Kent, D.V., and Opdyke, N.D.
1978: Paleomagnetism of the Devonian Catskill redbeds: evidence for motion of the coastal New England - Canadian Maritime region relative to cratonic North America. Journal of Geophysical Research, Volume 83, pages 4441-4450.

1979: The Early Carboniferous palaeomagnetic field of North America and its bearing upon tectonics of the northern Appalachians. Earth and Planetary Science Letters, Volume 44, pages 365-372.

Keppie, J.D.
1977: Tectonics of southern Nova Scotia. Nova Scotia Department of Mines, Paper 77-1, 21 pages.

1979: Geological map of the Province of Nova Scotia. Nova Scotia Department of Mines and Energy.

Keppie, J.D., Giles, P.S., and Boehner, R.C.
1978: Some Middle Devonian to Lower Carboniferous rocks of Cape George, Nova Scotia. Nova Scotia Department of Mines, Paper 78-4, 37 pages.

King, L.H., and Maclean, B.
1975: Stratigraphic interpretation of the central Grand Banks from high-resolution seismic reflection profiles. *In* Offshore Geology of Eastern Canada. Volume 2 - Regional Geology. *Edited by* W.J.M. van der Linden and J.A. Wade. Geological Survey of Canada, Paper 74-30, pages 175-186.

Kinsman, D.J.J.
1966: Gypsum and anhydrite of recent age, Trucial Coast, Persian Gulf. *In* Second Symposium on Salt. *Edited by* J.L. Rau. Northern Ohio Geological Society, Cleveland, Ohio, pages 302-320.

1969: Modes of formation, sedimentary associations, and diagnostic features of shallow-water and supratidal evaporites. Bulletin of the American Association of Petroleum Geologists, Volume 53, pages 830-840.

1976: Evaporites: relative humidity control of primary mineral facies. Journal of Sedimentary Petrology, Volume 46, pages 273-279.

Kinsman, D.J.J., and Park, R.K.
1976: Algal belt and coastal sabkha evolution, Trucial Coast, Persian Gulf. *In* Stromatolites. *Edited by* M.R. Walter. Developments in Sedimentology, 20. Amsterdam: Elsevier, pages 421-433.

Kirkham, R.V.
1978: Base metal and uranium distribution along the Windsor - Horton contact, central Cape Breton Island, Nova Scotia. Geological Survey of Canada, Paper 78-1B, pages 121-135.

Klappa C.F.
1979: Calcified filaments in Quaternary calcretes: organo-mineral interactions in the subaerial vadose environment. Journal of Sedimentary Petrology, Volume 49, pages 955-968.

Klein, G.de.V.
1974: Estimating water depths from analysis of barrier island and deltaic sedimentary sequences. Geology, Volume 2, pages 409-412.

1975: Sandstone Depositional Models for Exploration For Fossil Fuels. Illinois: Continuing Education Publishing Company, 109 pages.

Knapp, D., Kennedy, D. and Martineau, Y.
1979: Stratigraphy, structure and regional correlation of rocks at Grand Lake, Western Newfoundland. Current Research, Part A, Geological Survey of Canada, Paper 79-1A, pages 317-325.

Knight, I.
1975: Geological mapping, Carboniferous rocks, Cape Anguille Mountains, southwest Newfoundland. *In* Report of Activities for 1974. *Edited by* J.M. Fleming. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 75-1, pages 31-40.

1976: Geology of the Carboniferous of the Codroy Valley and northern Anguille Mountains. *In* Report of Activities for 1975. *Edited by* B.A. Greene. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 76-1, pages 10-18.

Knight, I., and Fong, C.C.K.
1975: St. Fintan's - Dashwoods Pond. Mineral Development Division, Newfoundland Department of Mines and Energy, Map 773.

Kraft, J.C.
1978: Coastal stratigraphic sequences. *In* Coastal Sedimentary Environments. *Edited by* R.A. Davis, Jr. New York: Springer-Verlag, pages 361-383.

Lambert, A.M., Kelts, K.R., and Marshall, N.F.
1976: Measurements of density underflows from Walensee, Switzerland. Sedimentology, Volume 23, pages 87-105.

Land, L.S., and Goreau, T.R.
1970: Submarine lithification of Jamaican reefs. Journal of Sedimentary Petrology, Volume 40, pages 457-462.

Lattman, L.H.
1973: Calcium carbonate cementation of alluvial fans in southern Nevada. Bulletin of the Geological Society of America, Volume 84, pages 3013-3028.

Leeder, M.R.
1973: Fluviatile fining-upwards cycles and the magnitude of palaeochannels. Geological Magazine, Volume 110, pages 265-276.

1974: Lower Border Group (Tournaisian) fluvio-deltaic sedimentation and palaeogeography of the Northumberland Basin. Proceedings of the Yorkshire Geological Society, Volume 40, pages 129-180.

1975: Pedogenic carbonate and flood sediment accretion rates: a quantitative model for alluvial, arid-zone lithofacies. Geological Magazine, Volume 112, pages 257-270.

1976: Sedimentary facies and the origins of basin subsidence along the northern margin of the supposed Hercynian Ocean. Tectonophysics, Volume 36, pages 167-179.

1978: A quantitative stratigraphic model for alluvium, with special reference to channel deposit density and interconnectedness. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 587-596.

LeFort, J.P., and van der Voo, R.
1981: A kinematic model for the collision and complete suturing between Gondwanaland and Laurussia in the Carboniferous. Journal of Geology, Volume 89, pages 537-550.

Lensen, G.J.
1958: A method of graben and horst formation. Geological note. Journal of Geology, Volume 66, pages 579-589.

Leopold, L.B., Wolman, M.G. and Miller, J.P.
1964: Fluvial Processes in Geomorphology. San Francisco: W.H. Freeman and Company.

Levy, Y.
1977a: The origin of brine in coastal sabkhas, northern Sinai. Journal of Sedimentary Petrology, Volume 47, pages 451-462.

1977b: Description and mode of formation of the supratidal evaporite facies in northern Sinai coastal plain. Journal of Sedimentary Petrology, Volume 47, pages 463-474.

Lewis, K.B.
1971: Slumping on a continental slope inclined at 1-4°. Sedimentology, Volume 16. pages 97-110.

Liebermann, O.
1967: Synthesis of dolomite. Nature, Volume 213, pages 241-245.

Link, M.H., and Osborne, R.H.
1978: Lacustrine facies in the Pliocene Ridge Basin Group, Ridge Basin, California. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M. Tucker. International Association of Sedimentologists, Special Publication 2, Blackwell Scientific Publications, pages 167-185.

Little, H.W. and Durham, C.C.
1971: Uranium in stream sediments in Carboniferous rocks of Nova Scotia. Geological Survey of Canada, Paper 70-54, 17 pages.

Livingston, D.A.
1965: Sedimentation and the history of water level change in Lake Tanganyika. Limnology and Oceanography, Volume 10, pages 607-610.

Logan, B.W.
1974: Inventory of diagenesis in Holocene - Recent Carbonate sediments, Shark Bay, Western Australia. *In* Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Memoir 22, pages 195-249.

Logan, B.W., Hoffman, P., and Gebelein, C.F.
1974: Algal mats, cryptalgal fabrics and structures, Hamelin Pool, Western Australia. American Association of Petroleum Geologists, Memoir 22, pages 140-194.

Logan, B.W., Rezak, R., and Ginsburg, R.N.
1964: Classification and environmental significance of algal stromatolites. Journal of Geology, Volume 72, pages 68-83.

Longman, M.W.
1980: Carbonate diagenetic textures from near surface diagenetic environments. Bulletin of the American Association of Petroleum Geologists, Volume 64, pages 461-485.

Loring, D.H.
1975: Surficial geology of the Gulf of St. Lawrence. *In* Offshore Geology of Eastern Canada, Volume 2 - Regional Geology. *Edited by* W.J.M. van der Linden and J.A. Wade. Geological Survey of Canada, Paper 74-30, pages 11-34.

Lowdon, J.A., Stockwell, C.H., Tipper, H.W., and Wanless, R.K.
1963: Age determinations and geological studies. Geological Survey of Canada, Paper 62-17, pages 117-118.

Lowe, D.R.
1975: Water escape structures in coarse-grained sediments. Sedimentology, Volume 22, pages 157-204.

Lowe, D.R., and LoPiccolo, R.D.
1974: The characteristics and origins of dish and pillar

structures. Journal of Sedimentary Petrology, Volume 44, pages 484-501.

Lucia, F.J.
1972: Recognition of evaporite-carbonate shoreline sedimentation. *In* Recognition of Ancient Sedimentary Environments. *Edited by* J.K. Rigby and W.K. Hamblin. Society of Economic Paleontologists and Mineralogists, Special Publication 16, pages 160-191.

Ludlam, S.D.
1967: Fayetteville Green Lake, New York, III. The laminated sediments. Limnology and Oceanography, Volume 14, pages 848-857.

1974: Fayetteville Green Lake, New York, IV. The role of turbidity currents in lake sedimentation. Limnology and Oceanography, Volume 19, pages 656-664.

MacLean, H.J.
1946: South Branch coal prospect. Unpublished Memorandum, Buchans Mining Company, Open File 110/13.

MacDonald, C.J.D.
1975: Reports on claim numbers 7123-7143, Codroy Pond area. Unpublished report, Noranda Exploration Company, Open File 12B/2 (194).

Maiklem, W.R., Bebout, D.G., and Glaister, R.P.
1969: Classification of anhydrite - a practical approach. Bulletin of Canadian Petroleum Geology, Volume 17, pages 194-233.

Mamet, B.L.
1968: Sur une microfaune du Viséan Superior de Terre Neuve. Naturaliste Canadien, Volume 95, pages 1357-1372.

1970: Carbonate microfacies of the Windsor Group (Carboniferous), Nova Scotia and New Brunswick. Geological Survey of Canada, Paper 70-21, 121 pages.

Marszalek, D.S.
1975: Calcisphere ultrastructure and skeletal aragonite from the algal Acetabularia Antillana. Journal of Sedimentary Petrology, Volume 45, pages 266-271.

Mayhew. M.A.
1974: 'Basement' to east coast continental margin of North America. Bulletin of the American Association of Petroleum Geologists, Volume 58, pages 1069-1088.

Mazzullo, S.J.
1973: Deltaic depositional environments in the Hamilton Group. (Middle Devonian), southeastern New York State. Journal of Sedimentary Petrology, Volume 43, pages 1061-1071.

McArthur, J.G.
1973: Barite and celestite deposits in Newfoundland. Paper presented at Annual Convention of the Prospectors and Developers Association, Toronto. Open File Nfld. 601.

McArthur, J.G., and Knight, I.
1974: Geology and industrial minerals of the Newfoundland Carboniferous. Field Trip Manual B-10. Geological Association of Canada and Mineralogical Association of Canada Annual Meeting, St. John's, Newfoundland, 43 pages.

McArthur, J.G., Davenport, P.H. and Howse, A.F.
1975a: A geochemical reconnaissance survey of the Carboniferous Codroy - Bay St. George Basin, Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Nfld. 787.

1975b: A geochemical reconnaissance survey of the Carboniferous Codroy - Bay St. George Basin, Newfoundland; Part II, Barium, strontium and manganese in stream sediments. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Nfld. 876.

McBride, E.F.
1962: Flysch and associated beds of Martinsburg Formation (Ordovician), central Appalachians. Journal of Sedimentary Petrology, Volume 32, pages 39-91.

1970: Flysch sedimentation in the Marathon Region, Texas. *In* Flysch Sedimentology in North America. *Edited by* J. Lajoie. Geological Association of Canada, Special Paper 7, pages 67-84.

McBride, E.F., Weidie, A.E., and Wolleben, J.A.
1975: Deltaic and associated deposits of Difunta Group (Late Cretaceous to Palaeocene), Parras and La Popa Basin, northeastern Mexico. *In* Deltas, Models for Exploration. *Edited by* M.L. Broussard. Houston Geological Society, pages 385-522.

McCabe, P.J.
1977: Deep distributary channels and giant beds formed in the Upper Carboniferous of the central Pennines, northern England. Sedimentology, Volume 24, pages 271-290.

McDonald, B.C., and Banerjee, I.
1971: Sediments and bedforms on a braided outwash plain. Canadian Journal of Earth Sciences, Volume 8, pages 1282-1301.

McGowen, J.H., and Garner, L.E.
1970: Physiographic features and stratification types of coarse-grained point bars: Modern and ancient examples. Sedimentology, Volume 14, pages 77-111.

McGowen, J.H., and Groat, C.G.
1971: Van Horn Sandstone, West Texas: an alluvial fan model for mineral exploration. Bureau of Economic Geology, University of Texas, Austin, Report of Investigations 72, 57 pages.

McKee, E.D.
1965: Experiments on ripple lamination. *In* Primary Sedimentary Structures and Their Hydrodynamic Interpretation. *Edited by* G.V. Middleton. Society of Economic Paleontologists and Mineralogists, Special Publication 12, pages 66-83.

McKee, E.D., Crosby, E.J., and Berryhill, H.L., Jr.
1967: Flood deposits, Bijou Creek, Colorado, June 1965. Journal of Sedimentary Petrology, Volume 37, pages 829-851.

McKerrow, W.S., and Zeigler, A.M.
1972: Silurian paleogeographic development of the Proto-Atlantic Ocean. 24th International Geological Congress, Section 6, pages 4-10.

McKillop, J.H.(with B.L. Smith)
1953a: St. Fintan's salt prospect - Diamond drill logs. Unpublished Report, Mineral Development Division, Newfoundland Department of Mines, Agriculture, and Resources, Open File 12B/2 (70).

McKillop, J.H.
1953b: Gypsum prospects, Ryans Brook, diamond drill logs. Newfoundland Department of Mines, Agriculture and Resources, unpublished report.

1955: Romaines Brook gypsum report based on field survey and diamond drill results. Newfoundland Department of Mines, Agriculture and Resources, unpublished report, Open File 12B/7 (66).

1957a: Flat Bay gypsum - diamond drill project, preliminary report. Newfoundland Department of Mines, Agriculture and Resources, unpublished report, Open File 12B/7 (68).

1957b: Gas and petroleum occurrences at Flat Bay, St. George's, Newfoundland. Newfoundland Geological Survey, unpublished report, Open File 12B/7 (84).

1959: Gypsum in Newfoundland. Newfoundland Department of Mines and Resources, Mines Branch, Mineral Resources Report 1, 24 pages.

McPherson, J.G.
1980: Genesis of variegated red beds in the fluvial Aztec siltstones (Late Devonian), southern Victoria Land, Antartica. Sedimentary Geology, Volume 27, pages 119-142.

Meckel, L.D.
1975: Holocene sand bodies in the Colorado delta area, northern Gulf of California. *In* Deltas, Models for Exploration. *Edited by* M.L. Broussard. Houston Geological Society, pages 239-265.

Miall, A.D.
1977: A review of the braided-river depositional environment. Earth-Science Reviews, Volume 13, pages 1-62.

1978: Lithofacies types and vertical profile models in braided river deposits: a summary. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, p. 597-604.

1979: Facies Model 5, Deltas. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada, Reprint Series 1, pages 43-56.

Middleton, G.V., and Hampton, M.A.
1973: Sediment gravity flows: mechanics of flow and deposition. *In* Turbidites and Deep Water Sedimentation. Society of Economic Paleontologists and Mineralogists, Pacific Section, Short Course, Anaheim, pages 1-38

1976: Subaqueous sediment transport and deposition by sediment gravity flows. *In* Marine Sediment Transport and Environmental Management. *Edited by* D.J. Stanley and D.J.P. Swift. New York: John Wiley and Sons, pages 197-218.

Monty, C.L.V.
1976: The origin and development of cryptalgal fabrics. *In* Stromatolites. *Edited by* M.R. Walter. Developments in Sedimentology, 20. Amsterdam: Elsevier, pages 193-249.

Moody-Stuart, M.
1966: High- and low-sinuosity stream deposits, with examples from the Devonian of Spitsbergen. Journal of Sedimentary Petrology, Volume 36, pages 1102-1117.

Moore, R.G.
1967: Lithostratigraphic units in the upper part of the Windsor Group, Minas subbasin, Nova Scotia. Geological Association of Canada, Special Paper 4, pages 245-266.

Moore, R.G., and Ryan, R.J.
1976: Guide to the invertebrate fauna of the Windsor Group in Atlantic Canada. Nova Scotia Department of Mines, Paper 76-5, 57 pages.

Morris, R.C.
1971: Classification and interpretation of disturbed bedding types in Jackfork flysch rocks (Upper Mississippian) Ouachita Mountains, Arkansas. Journal of Sedimentary Petrology, Volume 41, pages 410-424.

1974: Carboniferous rocks of the Ouachita Mountains, Arkansas: a study of facies patterns along the unstable slope and axis of a flysch trough. *In* Carboniferous of the Southeastern United States. *Edited by* G. Briggs. Geological Society of America, Special Paper 148, pages 241-280.

Müller, G., and Gees, R.A.
1970: Distribution and thickness of Quaternary sediments in the Lake

Constance basin. Sedimentary Geology, Volume 4, pages 81-87.

Müller, G., and Wagner, F.
1978: Holocene carbonate evolution in Lake Balaton (Hungary): a response to climate and impact of man. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication No. 2, Blackwell Scientific Publications, pages 55-80.

Müller, G., Irion, G., and Forstner, U.
1972: Formation and diagenesis of inorganic Ca-Mg carbonates in the lacustrine environment. Naturwissenschaften Volume 59, pages 158-164.

Multer, H.G., and Hoffmeister, J.E.
1968: Subaerial laminated crusts of the Florida Keys. *In* Field Guide To Some Carbonate Rock Environments, Florida Keys and Western Bahamas. Fairleigh Dickinson University, Madison New Jersey, pages 119-131.

Murray, A.
1873: Report on the Geological Survey for the year 1872. Geological Survey of Newfoundland.

Murray, A., and Howley, J.P.
1880: Geological Survey of Newfoundland, Reports for 1864 to 1880.

Murray, R.C.
1964: Origin and diagenesis of gypsum and anhydrite. Journal of Sedimentary Petrology, Volume 34., pages 512-523.

Mutti, E.
1977: Distinctive thin-bedded turbidite facies and related depositional environments in the Eocene Hecho Group (South-central Pyrenees, Spain). Sedimentology, Volume 24, pages 107-132.

Neale, E.R.W., and Kelley, D.G.
1960: Stratigraphy and structure of Mississippian rocks of northern Cape Breton Island. Proceedings of the Geological Association of Canada, pages 79-96.

Neev, D., and Emery, K.O.
1967: The Dead Sea - depositional processes and environment of evaporites. Geological Survey of Israel, Bulletin 41, 147 pages.

Neumann, A.C., Gebelein, C.D., and Scoffin, T.P.
1970: The composition, structure, and erodability of subtidal mats, Abaco, Bahamas. Journal of Sedimentary Petrology, Volume 40, pages 2744-297.

Neves, R. and Belt, E.S.
1970: Some observations on Namurian and Visean spores from Nova Scotia, Britain and Northern Spain. 6th International Congress of Carboniferous Stratigraphy and Geology, Sheffield, 1969, Comptes Rendus, Volume 11, pages 1233-1249.

Nijman, W., and Puigdefabregas, C.
1978: Coarse-grained point bar structure in a molasse-type fluvial system, Eocene Castisent Sandstone Formation, south Pyrennean Basin. *In* Fluvial Sedimentology. *Edited by* A.D Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 487-510.

Normark, W.R.
1974: Submarine canyons and fan valleys: factors affecting growth patterns of deep sea fans. *In* Modern and Ancient Geosynclinal Sedimentation. *Edited by* R.H. Dott, Jr. and R.H. Shaver. Society of Economic Paleontologists and Mineralogists, Special Publication 19, pages 56-68.

Normark, W.R., and Dickson, F.H.
1976a: Sublacustrine fan morphology in Lake Superior. Bulletin of the

American Association of Petroleum Geologists, Volume 60, pages 1021-1036.

1976b: Man-made turbidity currents in Lake Superior. Sedimentology, Volume 23, pages 815-832.

Northern Miner
1980: Pronto takes on potash bet on island of Newfoundland. Report, February 28th issue.

Northgate Exploration Ltd.
1979a: Project 735, Codroy South, Licence 1244. Report on geological, geochemical and geophysical surveys, 1979, Open File 110/14 (83).

1979b: Project 735, Codroy South, Licence 1245, NTS 110/14. Report on geological, geochemical and geophysical surveys, 1979, Open File 110/14 (82).

1979c: Project 735, Codroy North, Licence 1246. Report on geological, geochemical and geophysical surveys, 1979, Open File 110/14 (81).

O'Brien, F.
1975: The stratigraphy and palaeontology of the Clam Bank Formation and Long Point Formation of Port au Port Peninsula, Newfoundland. Unpublished M. Sc. Thesis, Memorial University of Newfoundland.

Ojany, F.F., and Ogenda, R.B.
1973: Kenya. A study in physical and human geography. Kenya: Longman.

Oomkens, E.
1970: Depositional sequences and sand distribution in the post-glacial Rhone delta complex. *In* Deltaic Sedimentation Modern and Ancient. *Edited by* J.P. Morgan and R.H. Shaver. Society of Economic Paleontologists and Mineralogists, Special Publication 15, pages 198-212.

Park, R.K.
1976: A note on the significance of lamination in stromatolites. Sedimentology, Volume 23, pages 379-393.

1977: The preservation potential of some recent stromatolites. Sedimentology, Volume 24, pages 485-506.

Phair, George
1949: Geology of the southwestern part of the Long Range, Newfoundland. Unpublished Ph. D. Thesis, Princeton University.

Phleger, F.B.
1969: A modern evaporite deposit in Mexico. Bulletin of the American Association of Petroleum Geologists, Volume 53, pages 824-829.

Picard, M.D., and High, L.R. Jr.
1973: Sedimentary structure of ephemeral streams. *In* Developments in Sedimentology, 17. Amsterdam: Elsevier, 223 pages.

Picha, F.
1978: Depositional and diagenetic history of Pleistocene and Holocene oolitic sediments and sabkhas in Kuwait, Persian Gulf. Sedimentology, Volume 25, pages 427-449.

Pittman, W.C., III
1978: Relationship between eustacy and stratigraphic sequences of passive margins. Bulletin of the Geological Society of America, Volume 89, pages 1389-1403.

Playford, G.
1963: Miospores from the Mississippian Horton Group, eastern Canada. Geological Survey of Canada, Bulletin 107, pages 1-47.

Playford, P.E., and Cockbain, A.E.
1976: Modern algal stromatolites at Hamelin Pool, a hypersaline barred basin in Shark Bay, Western

Australia. *In* Stromatolites. *Edited by* M.R. Walter. Developments in Sedimentology, 20. Amsterdam: Elsevier, pages 389-412.

Poole, W.H.
1967: Tectonic evolution of Appalachian region of Canada. *In* Hugh Lilly Memorial Volume. Geological Association of Canada, Special Paper Number 4, pages 9-51.

1976: Plate tectonic evolution of the Canadian Appalachian Region. Geological Survey of Canada, Paper 76-1B, pages 113-126.

Powers, M.C.
1953: A new roundness scale for sedimentary particles. Journal of Sedimentary Petrology, Volume 23, pages 117-119.

Prest, V.K., Steacy, H.R. and Bottrill, T.J.
1969: Occurrences of uranium and vanadium in Prince Edward Island. Geological Survey of Canada, Paper 68-74, 13 pages.

Purser, B.H., and Evans, G.
1973: Regional sedimentation along the Trucial Coast, S.E. Persian Gulf. *In* The Persian Gulf. *Edited by* B.H. Purser. Berlin: Springer-Verlag, pages 211-232.

Purser, B.H., and Loreau, J.P.
1973: Aragonitic, supratidal encrustations on the Trucial Coast, Persian Gulf. *In* The Persian Gulf. *Edited by* B.H. Purser. Berlin: Springer-Verlag, pages 343-376.

Ramsbottom, W.M.C.
1979: Rates of Transgression and regression in the Carboniferous of NW Europe. Journal of the Geological Society, Volume 136, pages 147-154.

Rast, N., and Grant, R.
1973: Transatlantic correlation of Variscan - Appalachian Orogeny. American Journal of Science, Volume 273, pages 572-579.

Ray, P.K.
1976: Structure and sedimentological history of the overbank deposits of a Mississippi River point bar. Journal of Sedimentary Petrology, Volume 46, pages 788-801.

Read, J.F.
1974: Calcrete deposits and Quaternary sediments, Edel Province, Shark Bay, Western Australia. *In* Evolution and Diagenesis of Quaternary Carbonate sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Memoir 22, pages 250-282.

1976: Calcretes and their distinction from stromatolites. *In* Stromatolites. *Edited by* M.R. Walter. Developments in Sedimentology, 20, Amsterdam: Elsevier, pages 55-71.

Reading, H.G.
1975: Strike slip fault systems; an example from the Cantabrians. IXth International Congress of Sedimentation, Nice, pages 287-293.

1980: Characteristics and recognition of strike-slip fault systems. *In* Sedimentation in Oblique-slip Mobile Zones. *Edited* by P.F. Ballance and H.G. Reading. International Association of Sedimentologists, Special Publication Number 4, Blackwell Scientific Publications, pages 7-26.

Reeves, C.C.
1970: Origin, classification and geologic history of caliche on the southern High Plains, Texas, and eastern New Mexico. Journal of Geology, Volume 78, pages 352-362.

Reineck, H.E.
1975: German North Sea Tidal Flats. In Tidal Deposits. A Casebook of Recent Examples and Fossil Counterparts. *Edited by* R.N. Ginsburg. New York: Springer-Verlag, pages 5-12.

Reineck, H.E., and Singh, I.B.
1967: Primary sedimentary structures in the recent sediments of the Jade Sea, North Sea. Marine Geology, Volume 5, pages 227-235.

1975: Depositional Sedimentary Environments. Berlin: Springer-Verlag, 439 pages.

Reineck, H.E., and Wunderlich, F.
1968: Classification and origin of flaser and lenticular bedding. Sedimentology, Volume 11, pages 99-104.

Reinson, G.E.
1979: Facies Model 6, Barrier Island Systems. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada Reprint Series 1, pages 57-74.

Renfro, A.R.
1974: Genesis of evaporite-associated stratiform metalliferous deposits - a sabkha process. Economic Geology, Volume 69, pages 33-45.

Ricci-Lucchi, F.
1975: Depositional cycles in two turbidite formations of the northern Apennines (Italy). Journal of Sedimentary Petrology, Volume 45, pages 34-43.

Richardson, K.A., and Holman, P.B.
1975: Airborne radioactivity map, St. George's Basin, Newfoundland. Geological Survey of Canada, Open File 270.

Riley, G.C.
1962: Stephenville map-area, Newfoundland. Geological Survey of Canada, Memoir 232, 72 pages.

Robbin, D.M., and Stipp, J.J.
1979: Depositional rate of laminated soil-stone crusts, Florida Keys. Journal of Sedimentary Petrology, Volume 49, pages 175-180.

Rodgers, J.
1965: Long Point and Clam Bank Formations, western Newfoundland. Proceedings of the Geological Association of Canada, Volume 16, pages [illegible]-94.

Rose, E.R.
1947: Summary report on salt exploration in the Heatherton area, west coast, Newfoundland, 1947. Geological Survey of Newfoundland, unpublished report, Open File 12B/7 (40).

1969: Vanadium occurrences in Canada. Geological Survey of Canada, Paper 66-57, 22 pages.

Roy, J.L.
1973: Latitude maps of the eastern North American - western European paleoblock. *In* Earth Science Symposium on Offshore Eastern Canada. *Edited by* P.J. Hood. Geological Survey of Canada, Paper 71-23, pages 3-22.

R.P.F. Syndicate
1980: Geological evolution, geophysics and drilling in the Fischells Brook area, Newfoundland. Confidential unpublished report.

Rust, B.R.
1972: Structure and process in a braided river. Sedimentology, Volume 18, pages 221-245.

1978: Depositional models for braided alluvium. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 605-625.

Ryder, R.T., Fouch, T.D., and Elison, J.H.
1976: Early Tertiary sedimentation in the western Uinta Basin, Utah. Bulletin of the Geological Society of America, Volume 87, pages 496-512.

Saarberg Interplan Canada Ltd.
1980: Assessment report (geology, geophysics, geochemistry) on Claim Block Licences numbered 1423, 1449, 1453, 1446, 1450, 12159, 1448, 1452, 12160, Codroy Valley. Confidential Unpublished report.

Sage, N.M.
1954: The stratigraphy of the Windsor Group in the Antigonish quadrangles and the Mahone Bay - St. Margaret Bay area, - Nova Scotia. Nova Scotia Department of Mines, Memoir 3.

Sandberg, P.A.
1975: New interpretations of Great Salt Lake ooids and of ancient non-skeletal carbonate mineralogy. Sedimentology, Volume 22, pages 497-537.

Sanders, J.E.
1968: Stratigraphy and primary sedimentary structures of fine-grained, well-bedded strata, inferred lake deposits, Upper Triassic, central and southern Connecticut. *In* Late Paleozoic and Mesozoic Continental Sedimentation, Northeastern North America. *Edited by* G. de V. Klein. Geological Society of America, Special Publication 106, pages 265-305.

Sargaent, W.A.S.
1975: Plant trace fossils. *In* The Study of Trace Fossils: A Synthesis of Principles, Problems and Procedures in Ichnology. *Edited by* R.W. Frey. New York: Springer-Verlag, pages 163-180.

Schafer, A., and Stapf, K.R.G.
1978: Permian Saar-Nahe Basin and recent Lake Constance (Germany): two environments of lacustrine algal carbonates. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication Number 2, Blackwell Scientific Publications, pages 81-106.

Schenk, P.E.
1967a: The Macumber Formation of the Maritime Provinces - a Mississippian analogue to Recent strand-line carbonates of the Persian Gulf. Journal of Sedimentary Petrology, Volume 37, pages 365-376.

1967b: The significance of algal stromatolites to paleoenvironmental and chronostratigraphic interpretations of the Windsorian Stage (Mississippian), Maritime Provinces. Geological Association of Canada, Special Paper 4, pages 229-243.

1969: Carbonate-sulfate-redbed facies and cyclic sedimentation of the Windsorian Stage (Middle Carboniferous) Maritime Provinces. Canadian Journal of Earth Sciences, Volume 6, pages 1037-1066.

1971: Southeastern Atlantic Canada, northwestern Africa and continental drift. Canadian Journal of Earth Sciences, Volume 8, pages 1218-1251.

1975: Carbonate-sulfate intertidalites of the Windsor Group (Middle Carboniferous), Maritime Provinces, Canada. *In* Tidal Deposits. A Casebook of Recent Examples and Fossil Counterparts. *Edited by* R.N. Ginsburg. New York: Springer-Verlag, pages 373-380.

1978: Synthesis of the Canadian Appalachians. IGCP Project 27, Canadian-Appalachian Orogen of the North Atlantic Region. Geological Survey of Canada, Paper 78-13, pages 111-136.

Schluger, P.R.
1976: Petrology and origin of the red beds of the Perry Formation, New Brunswick, Canada and Maine, U.S.A. Journal of Sedimentary Petrology, Volume 46, pages 22-37.

Scholle, P.A.
1978: A Color Illustrated Guide to Carbonate Rock Constituents, Textures, Cements and Porosities.

American Association of Petroleum Geologists, Memoir 27, 241 pages.

Scholle, P.A. and Kinsman, D.J.J.
1974: Aragonitic and high-Mg calcite caliche from the Persian Gulf - a modern analogy for the Permian of Texas and New Mexico. Journal of Sedimentary Petrology, Volume 44, pages 904-916.

Schneider, J.F.
1975: Recent tidal deposits, Abu Dhabi, UAE, Arabian Gulf. *In* Tidal Deposits: A casebook of recent examples and fossil counterparts. *Edited by* R.N. Ginsburg. New York: Springer-Verlag, pages 209-214.

Schreiber, B.C.
1978: Environments of subaqueous gypsum deposition. *In* Marine Evaporites. *Edited by* W.E. Dean and B.C. Schreiber. Society of Economic Paleontologists and Mineralogists, short course Number 4, Oklahoma City, pages 43-73.

Schreiber, B.C., and Kinsman, D.J.J.
1975: New observations on the Pleistocene evaporites of Montallegro, Sicily and modern analog. Journal of Sedimentary Petrology, Volume 45, pages 469-479.

Schreiber, B.C., Friedman, G.M., Decima, A., and Schreiber, E.
1976: Depositional environments of Upper Miocene (Messinian) evaporite deposits of the Silician Basin. Sedimentology, Volume 23, pages 729-760.

Schroeder, J.H.
1973: Submarine and vadose cements in Pleistocene Bermuda reef rocks. Sedimentary Geology, Volume 10, pages 179-204.

Schuchert, C. and Dunbar, C.O.
1934: Stratigraphy of western Newfoundland. Geological Society of America, Memoir 1, 123 pages.

Scoffin, T.P.
1970: The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini lagoon, Bahamas. Journal of Sedimentary Petrology, Volume 40, pages 249-273.

Sharp, R.P., and Noble, L.M.
1953: Mudflow of 1941 at Wrightwood, Southern California. Bulletin of the Geological Society of America, Volume 64, pages 547-560.

Shea, F.S.
1966: Lower Carboniferous stratigraphy of the Windsor-Horton District of Nova Scotia. *In* Guidebook, Geology of Parts of Atlantic Provinces. Geological Association of Canada, pages 99-106.

Shearer, J.M.
1973: Bedrock and surficial geology of the northern Gulf of St. Lawrence as interpreted from continuous seismic reflection profiles. *In* Earth Science Symposium on Offshore Eastern Canada. *Edited by* P.J. Hood. Geological Survey of Canada, Paper 71-23, pages 285-303.

Shearman, D.J.
1966: Origin of marine evaporites by diagenesis. Transactions of the Institute of Mining and Metallurgy, Series B, Volume 75, pages 208-215.

1970: Recent halite rock, Baja California, Mexico. Transactions of the Institute of Mining and Metallurgy, Series B, Volume 79, pages 155-162.

1978: Evaporites of coastal sabkhas. *In* Marine Evaporites. *Edited by* W.E. Dean and B.C. Schreiber. Society of Economic Paleontologists and Mineralogists, short course Number 4, Oklahoma City, pages 6-42.

Shearman, D.J., and Fuller, J.G.C.M.
1969: Anhydrite diagenesis, calcitization, and organic

laminites, Winnipegosis Formation, Middle Devonian, Saskatchewan. Bulletin of Canadian Petroleum Geology, Volume 17, pages 496-525.

Shell Canada Resources Ltd.
1981a: Report on geological mapping, prospecting and geochemical sampling work, 110/14. Licence No. 1245. Confidential unpublished report.

1981b: Report on geological mapping, prospecting and geochemical sampling work, Reid Lots 6, 7, 8, 9, 11, 13, 17 and 21. 11/O, 12/B. Confidential unpublished report.

1981c: Report on radiometric survey, 1980. Reid Lot 5, 110/14, 15. Confidential unpublished report.

1981d: Summary report, uranium exploration, Codroy - St. George's Basin. Confidential unpublished report.

Shelton, J.W., and Noble, R.L.
1974: Depositional features of braided-meandering stream. Bulletin of the American Association of Petroleum Geologists, Volume 58, pages 742-749.

Shepard, R.G.
1975 (*in* Baker 1977): Geomorphic operation, evolution and equilibrium, Sandy Creek Watershed, Llano region, central Texas. Unpublished Ph.D. dissertation, University of Texas, Austin, 209 pages.

Sheridan, R.E., and Drake, C.
1968: Seaward extension of the Canadian Appalachians. Canadian Journal of Earth Sciences, Volume 5, pages 337-373.

Shinn, E.A.
1968: Practical significance of birdseye structures in carbonate rocks. Journal of Sedimentary Petrology, Volume 38, pages 215-223.

1969: Submarine lithification of Holocene carbonate sediments in the Persian Gulf. Sedimentology, Volume 12, pages 109-144.

1973: Sedimentary accretion along the leeward, SE coast of Qatar Peninsula, Persian Gulf. *In* The Persian Gulf. *Edited by* B.H. Purser. Berlin: Springer-Verlag, pages 199-209.

Shinn, E.A., Lloyd, R.M., and Ginsburg, R.N.
1969: Anatomy of a modern carbonate tidal flat, Andros Island, Bahamas. Journal of Sedimentary Petrology, Volume 39, pages 1202-1228.

Simons, D.B., Richardson, E.V., and Nordin, C.F.
1965: Sedimentary structures generated by flow in alluvial channels. *In* Primary Sedimentary Structures and Their Hydrodynamics Interpretation. *Edited by* G.V. Middleton. Society of Economic Paleontologists and Mineralogists, Special Publication 12, pages 34-52.

Smith, A.G., Briden, J.C., and Drewery, G.E.
1973: Phanerozoic world maps. *In* Organisms and Continents Through Time. *Edited by* N.F. Hughes. Geological Society of London, Special Papers in Palaeontology, 12, pages 1-39.

Smith, B.L.
1953: Brine seeps south of St. Fintan's, Newfoundland. Geological Survey of Newfoundland, unpublished report, Open file 12B/2 (59).

Smith, D.B.
1971: Possible displacive halite in the Permian Upper Evaporite Group of northeast Yorkshire. Sedimentology, Volume 17, pages 221-232.

Smith, N.D.
1970: The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians. Bulletin of the Geological Society of America, Volume 81, pages 2993-3014.

1971: Transverse bars and braiding in the Lower Platte River, Nebraska. Bulletin of the Geological Society of America, Volume 82, pages 3407-3420.

1972: Some sedimentological aspects of planar cross-stratification in a sandy braided river. Journal of Sedimentary Petrology, Volume 42, pages 624-634.

1974: Sedimentology and bar formation in the Upper Kicking Horse River, a braided outwash stream. Journal of Geology, Volume 82, pages 205-224.

Smoot, J.P.
1978: Origin of the carbonate sediments in the Wilkins Peak Member of the lacustrine Green River Formation (Eocene), Wyoming, U.S.A. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication Number 2, Blackwell Scientific Publications, pages 107-126.

Smyth, W.R., and Schillereff, H.S.
1982: The pre-Carboniferous geology of southwest White Bay. *In* Curent Research. *Edited by* C.F. O'Driscoll and R.V. Gibbons. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 82-1, pages 78-98.

Sneh, A.
1979: Late Pleistocene fan-deltas, along the Dead Sea rift. Journal of Sedimentary Petrology, Volume 49, pages 541-552.

Southard, J.B.
1975: Bed configurations in depositional environments as interpreted from primary sedimentary structures and stratification sequences. Society of Economic Paleontologists and Mineralogists, short course Number 2, Dallas, pages 5-44.

Spector, A.
1969: Report on interpretation of aeromagnetic data, St. Georges Bay, Newfoundland. British Newfoundland Exploration Company Ltd. Unpublished report, Open File 12B (157).

Stacy, M.C.
1953: Stratigraphy and paleontology of the Windsor Group (Upper Mississippian) in parts of Cape Breton Island, Nova Scotia. Nova Scotia Department of Mines, Memoir 2.

Stauffer, P.H.
1967: Grain flow deposits and their implications, Santa Ynez Mountains, California. Journal of Sedimentary Petrology, Volume 37, pages 487-508.

Steel, R.J.
1973: Cornstone (fossil caliche), its origin, stratigraphic, and sedimentological importance in the New Red Sandstone, western Scotland. Journal of Geology, Volume 82, pages 351-369.

1974: New Red Sandstone floodplain and piedmont sedimentation in the Hebridean Province. Journal of Sedimentary Petrology, Volume 44, pages 336-357.

Steel, R.J. and Aasheim, S.M.
1978: Alluvial sand deposition in a rapidly subsiding basin (Devonian, Norway). *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, pages 385-412.

Steel, R.J., and Wilson, A.C.
1975: Sedimentation and tectonism

(Permo-Triassic) on the margin of the North Minch Basin, Lewis. Journal of the Geological Society of London, Volume 131, pages 183-202.

Steel, R.J., Maehle, S., Nilsen, S.L., and Spinnangr, A.
1977: Coarsening-upward cycles in the alluvium of Horneten Basin (Devonian), Norway: sedimentary responses to tectonic events. Bulletin of the Geological Society of America, Volume 88, pages 1124-1134.

Steinmetz, R.
1967: Depositional history, primary sedimentary structures, crossbed dips, and grain size of an Arkansas river point bar at Wekiwa, Oklahoma. Report F67-G-3. *In* Depositional Sedimentary Environments. *Edited by* H.S. Reineck and I.B. Singh. Berlin: Springer-Verlag, 1975.

Stephen, M.F., and Gorsline, D.S.
1975: Sedimentary aspects of the New River Delta, Salton Sea, Imperial County, California. *In* Deltas, Models for Exploration. *Edited by* M.L. Broussard. Houston Geological Society, pages 267-282.

Stevens, R.K., and Knight I.
1974: Economic geology of west Newfoundland. *In* Report of Activities for 1973. *Edited by* W.R. Smyth. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 74-1, pages 50-51.

Stürm, M. and Matter, A.
1978: Turbidites and varves in Lake Brienz (Switzerland): deposition of clastic detritus by density currents. *In* Modern and Ancient Lake Sediments. *Edited by* A. Matter and M.E. Tucker. International Association of Sedimentologists, Special Publication Number 2, Blackwell Scientific Publications, pages 145-168.

Summers, W.F.
1948: Report on the geology and diamond drilling operations in the St. George's coalfield area, Newfoundland, in the summer of 1947. Geological Survey of Newfoundland, unpublished report, Open File 12B/2 (41).

Sutton, R.G., Bowen, Z.P., and McAlester, A.L.
1970: Marine shelf environments of the Upper Devonian Sonyea Group of New York. Bulletin of the Geological Society of America, Volume 81, pages 2975-2992.

Tanner, W.F.
1967: Ripple mark indices and their uses. Sedimentology, Volume 9, pages 89-104.

Taylor, J.C.M., and Illing, L.V.
1969: Holocene intertidal calcium carbonate cementation, Qatar, Persian Gulf. Sedimentology, Volume 12, pages 69-107.

Taylor, R.P., Strong, D.F., and Kean, B.F.
1980: The Topsails igneous complex: Silurian-Devonian peralkaline magmatism in western Newfoundland. Canadian Journal of Earth Sciences, Volume 17, pages 425-439.

Taylor, W.R.
1970: Geology and geochemistry of a uranium-rich area in southwestern Newfoundland. Unpublished M.Sc. Thesis, Memorial University of Newfoundland, 66 pages.

Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A.
1976: Applied Geophysics. Cambridge University Press, 700 pages.

Tunbridge, I.P.
1981a: Sandy high-energy flood sedimentation - some criteria for recognition with an example from the

Devonian of S.W. England. Sedimentary Geology, Volume 28, pages 79-95.

1981b: Old Red Sandstone sedimentation - an example from the Brownstones (highest Lower Old Red Sandstone) of South Central Wales. Geological Journal, Volume 16, pages 111-124.

Twenhofel, W.H., and MacClintock, P.
1940: Surface of Newfoundland. Bulletin of the Geological Society of America, Volume 51, pages 1665-1728.

Union-Brinex
1973: Geological report, Union-Brinex Anguille H-98. Union Oil Co., unpublished company report, Open File 110/14 (53).

Upadhyay, H.D.
1973: The Betts Cove ophiolite and related rocks of the Snooks Arm Group, Newfoundland. Unpublished Ph.D. Thesis, Memorial University of Newfoundland.

Utting, J.
1966: Geology of the Codroy Valley, southwestern Newfoundland, including results of a preliminary palynological investigation. Unpublished M. Sc. Thesis, Memorial University of Newfoundland, 89 pages.

1977: Preliminary palynological investigation of the Windsor Group (Mississippian) of Nova Scotia. *In* Report of Activities, Part A. Geological Survey of Canada, Paper 77-1A, pages 347-349.

1978: Palynological zonation of the Windsor Group (Mississippian) in Cape Breton Island, Nova Scotia. *In* Current Research, Part A. Geological Survey of Canada, Paper 78-1A, pages 205-207.

1980: Palynology of the Windsor Group (Mississippian) in a borehole at Stewiacke, Shubenacadie Basin, Nova Scotia. Canadian Journal of Earth Sciences, Volume 17, pages 1031-1045.

Vanderveer, D.G.
1975: Surficial and glacial mapping, southwest Newfoundland. *In* Report of Activities for 1974. *Edited by* J.M. Fleming. Mineral Development Division, Newfoundland Department of Mines and Energy, Report 75-1, pages 88-91.

van der Voo, R., French, A.N., and French, R.B.
1979: A palaeomagnetic pole position from the folded upper Devonian Catskill red beds, and its tectonic implications. Geology, Volume 7, pages 345-348.

van Houten, F.B.
1973: Origin of red beds - a review, 1961-1972. Earth and Planetary Science, Annual Review, Volume 1, pages 39-61.

1976: Late Variscan nonmarine deposits, Northwestern Africa: implications for pre-drift, North Atlantic reconstructions. American Journal of Science, Volume 276, pages 671-693.

Varma, C.P.
1969: Lower Carboniferous miospores from the Albert oil shales (Horton Group) of New Brunswick, Canada. Micropaleontology, Volume 15, pages 301-324.

1954a: Preliminary report on the gravity survey of southwest Newfoundland. Newfoundland Department of Mines, Agriculture and Resources, unpublished report, Open File 12B (62).

1954b: Gravity survey of Bay St. George area, southwest Newfoundland. Geological Survey of Newfoundland, unpublished report, Open File 12B (63).

Visher, G.S.
1972: Physical characteristics of fluvial deposits. *In* Recognition of Ancient Sedimentary Environments. *Edited by* J.K. Rigby and W.K. Hamblin. Society of Economic Paleontologists and Mineralogists, Special Publication 16, pages 84-97.

von Bitter, P.H.
1975: Palaeoecology and biostratigraphy of Mississippian (Windsor Group) conodonts, Newfoundland and Cape Breton Island, Canada. Abstract, Geological Society of America, Waterloo, page 875.

von Bitter, P.H., and Plint-Geberl, H.A.
1978: Conodont biostratigraphy of the lower Codroy Group (Lower Carboniferous), western Newfoundland. Abstract, Eastern Canada Palaeontology and Biostratigraphy seminar, Corner Brook.

1979: Conodont biostratigraphy of the Lower Codroy Group (Lower Carboniferous), western Newfoundland, Canada. Abstract, 9th International Congress of Carboniferous Stratigraphy and Geology, Urbana, Illinois, pages 223-224.

1982: Conodont biostratigraphy of the Codroy Group (Lower Carboniferous), western Newfoundland, Canada. Canadian Journal of Earth Sciences, Volume 19, pages 193-221.

von der Borch, C.C.
1976: Stratigraphy and formation of Holocene dolomitic carbonate deposits of the Coorong area, South Australia. Journal of Sedimentary Petrology, Volume 46, pages 952-966.

von Der Borch, C.C., and Shock, D.
1979: Geological significance of Coorong dolomites. Sedimentology, Volume 26, pages 813-824.

Walker, R.G.
1966a: Shale Grit and Grindslow Shales: transition from turbidite to shallow water sediments in the Upper Carboniferous of northern England. Journal of Sedimentary Petrology, Volume 36, pages 90-114.

1966b: Deep channels in turbidite-bearing formations. Bulletin of the American Association of Petroleum Geologists, Volume 50, pages 1899-1917.

1967: Turbidite sedimentary structures and their relationship to proximal and distal depositional environments. Journal of Sedimentary Petrology, Volume 37, pages 25-43.

1969: The juxtaposition of turbidite and shallow-water sediments: study of a regressive sequence in the Pennsylvanian of North Devon, England. Journal of Geology, Volume 77, pages 125-143.

1970: Reivew of the geometry and facies organization of turbidites and turbidite-bearing basins. *In* Flysch Sedimentology in North America. *Edited by* J. Lajoie. Geological Association of Canada, Special Paper 7, pages 219-251.

1975a: Conglomerates: sedimentary structures and facies models. *In* Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences. Society of Economic Paleontologists and Mineralogists, short course Number 2, Dallas, pages 133-161.

1975b: Generalized facies models for resedimented conglomerates of turbidite association. Bulletin of the Geological Society of America, Volume 86, pages 737-748.

1978: Deep-water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. Bulletin of the American Association of Petroleum Geologists, volume 62, pages 932-966.

1979a: Facies Models 3, Sandy Fluvial Systems. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada Reprint Series 1, pages 23-31.

1979b: Facies Models 8, Turbidites and associated coarse clastic deposits. *In* Facies Models. *Edited by* R. G. Walker. Geoscience Canada Reprint Series 1, pages 91-104.

Walker, R.G., and Harms, J.C.
1971: The 'Catskill Delta'; a prograding muddy shoreline in central Pennsylvannia. Journal of Geology, Volume 79, pages 381-399.

Walker, R.G., and Mutti, E.
1973: Turbidite facies and facies associations. *In* Turbidites and Deep Water Sedimentation. Society of Economic Paleontologists and Mineralogists, Pacific Section, Short Course, Anaheim, pages 119-157.

Walker, T.R.
1963: In situ formation of red beds in an arid to semi-arid climate. Abstract, Geological Society of America, Special Paper 76, pages 174-175.

1967a: Formation of red beds in modern and ancient deserts. Bulletin of the Geological Society of America, Volume 78, pages 353-368.

1967b: Color of recent sediments in tropical Mexico: a contribution to the origin of red beds. Bulletin of the Geological Society of America, Volume 78, pages 917-920.

Wall, R.A., Harris, W.B., *and*
Nunan, W.E.
1975: Calcareous crust (caliche) profiles and early sub-aerial exposure of Carboniferous carbonates, northeastern Kentucky. Sedimentology, Volume 22, pages 417-440.

Wardlaw, N.C., and Schwerdtner, W.M.
1966: Halite-anhydrite seasonal layers in Middle Devonian Prairie evaporite formation, Saskatchewan, Canada. Bulletin of the Geological Society of America, Volume 77, pages 331-342.

Watts, A.B.
1972: Geophysical investigations east of the Magdalen Islands, southern Gulf of St. Lawrence. Canadian Journal of Earth Sciences, Volume 9, pages 1504-1528.

Webb, G.W.
1969: Paleozoic wrench faults in Canadian Appalachians. *In* North Atlantic Geology and Continental Drift. *Edited by* M. Kay. American Association of Petroleum Geologists, Memoir 12, pages 754-786.

Wescott, W.A., and Ethridge, F.G.
1980: Fan-delta sedimentology and tectonic setting - Yallahs fan delta, southeast Jamaica. Bulletin of the American Association of Petroleum Geologists, Volume 64, pages 374-399.

Westfield Minerals Ltd.
1975: Induced polarisation survey, Bald Mountain to Highlands area, Newfoundland. Two unpublished reports, Open File 12B/2 (197).

1979a: Report on exploration in 1979 - Codroy Basin, Newfoundland. Reid Lots 6, 7, 8, 9, 11, 13, 17 and 21. Confidential unpublished reports.

1979b: Results of a reconnaissance geochemical and ground radiometric survey on Reid Lots 6, 7, 8, 9, 11, 13, 17 and 21. Confidential unpublished reports.

Widmer, K.
1950: Geology of the Hermitage Bay area, Newfoundland. Unpublished Ph.D. Thesis, Princeton University.

Wilcox, R.E., Harding, T.P., and Seely, D.R.
1973: Basic wrench tectonics. Bulletin of the American Association of Petroleum Geologists, Volume 57, pages 74-96.

Williams, B.F., and Rust, B.R.
1969: The sedimentology of a braided river. Journal of Sedimentary Petrology, Volume 39, pages 649-679.

Williams, E.P.
1974: Geology and petroleum possibilities in and around Gulf of St. Lawrence. Bulletin of the American Association of Petroleum Geologists, Volume 58, pages 1137-1155.

Williams, G.E.
1966: Planar cross-stratification formed by the lateral migration of shallow streams. Journal of Sedimentary Petrology, Volume 36, pages 742-746.

1967: Formation of large-scale, trough cross-stratification in a fluvial environment. Journal of Sedimentary Petrology, Volume 37, pages 136-140.

1971: Flood deposits of the sand-bed ephemeral streams of central Australia. Sedimentology, Volume 17, pages 1-40.

Williams, H.
1978: Tectonic lithofacies map of the Appalachian Orogen. Memorial University of Newfoundland Map Number 1.

Williams, H., Kennedy, M.J., and Neale, E.R.W.
1972: The Appalachian structural province. *In* Tectonic Styles in Canada. *Edited by* R.A. Price and R.J.W. Douglas. Geological Association of Canada, Special Paper 11, pages 181-261.

1974: The northeastward termination of the Appalachian orogen. *In* The Ocean Basins and Margins, Volume 2 - North Atlantic. *Edited by* A.E.M. Nairn and F.G. Stehli. New York: Plenum, pages 79-123.

Wilson, J.T.
1962: Cabot fault, an Appalachian equivalent of the San Andreas and Great Glen faults and some implications for continental displacement. Nature, Volume 195, pages 135-138.

Wolman, M.G., and Miller, J.P.
1960: Migmitude and frequency of forces in geomorphic processes. Journal of Geology, Volume 68, pages 56-74.

Wright, L.D.
1978: River Deltas. *In* Coastal Sedimentary Environments. *Edited by* R.A. Davis Jr. New York: Springer-Verlag, pages 5-64.

POOR

QUALITY

ORIGINAL

MINERAL DEVELOPMENT DIVISION
DEPARTMENT OF MINES AND ENERGY
GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

DEPARTMENT
DEPARTMENT
GOVERNMENT

MAP 82-1

GEOLOGY OF T
CARBONIFEROUS BAY ST. GE

Scale 1:125,000

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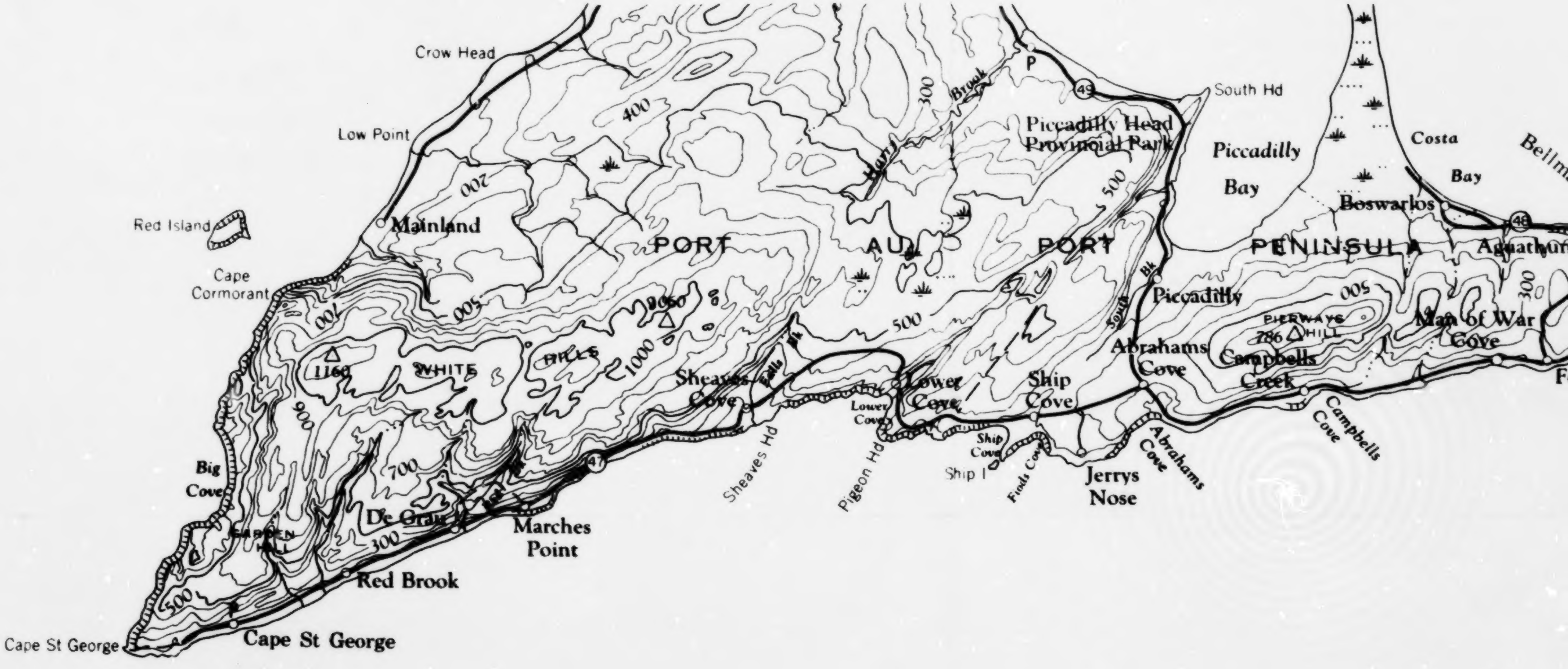
48°45'
30'
59°00'
Crow Head
Low Point
Red Island
Cape Cormorant
Mainland
Big Cove
Cape St George
Cape St George
Red Brook
De Grau
Marches Point
GARDEN HILL
WHITE
HILLS
PORT
AU
PORT
PENINSULA
1160
1060
Sheaves Cove
Sheaves Hd
Lower Cove
Lower Cove
Pigeon Hd
Ship Cove
Ship Cove
Ship I
Jerrys Nose
Abrahams Cove
Abrahams Cove
Campbells Creek
Campbells Cove
Piccadilly
Piccadilly Head Provincial Park
Piccadilly Bay
South Hd
Boswarlos
Costa Bay
PIERWAYS HILL
786
Man of War Cove
Brook
South Bk
47
48
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OPMENT DIVISION
MINES AND ENERGY
NEWFOUNDLAND AND LABRADOR

DEPARTMENT OF ENERGY, MINES AND RESOURCES
DEPARTMENT OF REGIONAL ECONOMIC EXPANSION
GOVERNMENT OF CANADA

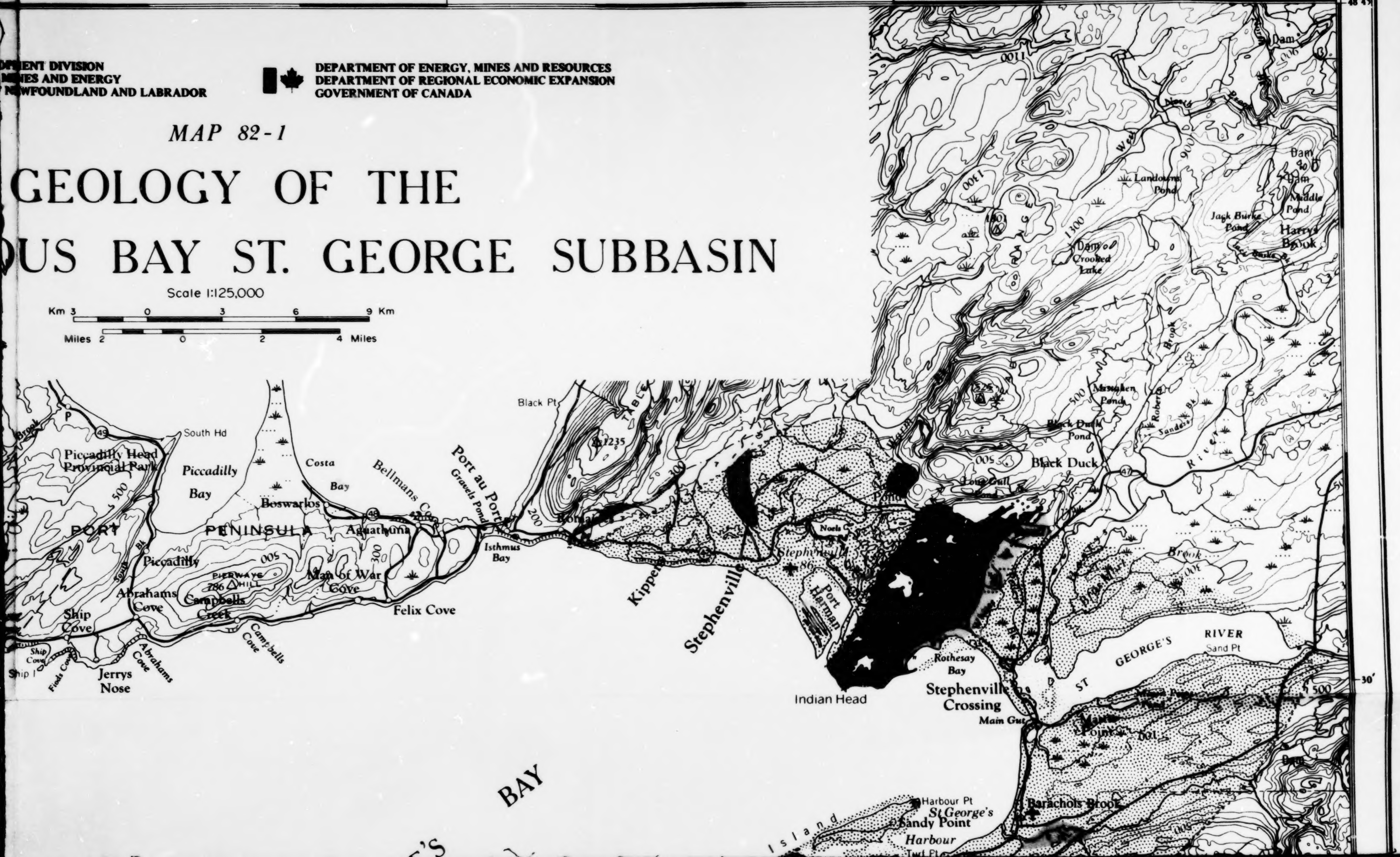
MAP 82-1

GEOLOGY OF THE
US BAY ST. GEORGE SUBBASIN

Scale 1:125,000

Km 3 0 3 6 9 Km

Miles 2 0 2 4 Miles


45'
30'
58°15'
48°45'
30'
Dam
North Brook
Landowns Pond
Jack Burke Pond
Middle Pond
Harrys Brook
Crooked Lake
Mistaken Ponds
Black Duck Pond
Black Duck
Long Gull Pond
Roberts Bk
Sanders Bk
River
Black Pt
Table
South Hd
Piccadilly Head Provincial Park
Piccadilly Bay
Costa Bay
Bellmans Cove
Port au Port
Gravels Pond
Boswarlos
Aguathuna
PORT PENINSULA
Isthmus Bay
Piccadilly
South Bk
PIEWAYS HILL
Man of War Cove
Felix Cove
Abrahams Cove
Campbells Creek
Campbells Cove
Ship Cove
Ship I
Fiords Cove
Jerrys Nose
Kippens
Stephenville
Noels Pond
Port Harmon
Indian Head
Rothesay Bay
Stephenville Crossing
Main Gut
ST GEORGE'S RIVER
Sand Pt
Harbour Pt
St George's Harbour
Sandy Point
Island
Barachois Brook
BAY
1235
1300
500
300
200
286

Cape St George
Cape St George

SYMBOLS

Drift covered area	▨
Geological boundary (defined, approximate, assumed)	
Unconformity	
Bedding, tops known (horizontal, inclined, vertical, overturned)	
Bedding, tops unknown (inclined, vertical)	
Cleavage (inclined)	
Minor folds (plunge indicated)	
Structural trend (from air photographs)	
Lineament (from air photographs)	
Fault (defined, approximate, assumed)	
Fault (inclined, vertical)	
Fault (solid circle indicates downthrown side, arrows indicate relative movement	
Thrust fault, teeth in direction of dip (defined, approximate, assumed)	
Anticline (defined, approximate)	
Syncline(defined, approximate)	
Anticline and syncline (overturned)	
Mineral occurrence (copper)	×Cu
Dry hole (abandoned)	◇
Salt spring	ss○
Fossil locality	Ⓕ
Diamond drill hole	DDH ●
Sinkhole	○ SH
Trace of coal seam	/
Mine (operating, abandoned)	⚒ ⚒
Rock outcrop	×
Structural cross-sections	C - C'
Structural cross-sections illustrated in text	A - A'

Geological compilation by Ian Knight (1979).

Geological cartography by Mineral Development Division, Department of Mines and Energy, Government of Newfoundland and Labrador.

Copies of this map may be obtained from the Publications and Information Section, Mineral Development Division, Department of Mines and Energy, P.O. Box 4750, St. John's, Newfoundland AIC 5T7.

Base maps enlarged from 1:250,000 scale base maps published by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, 1971.

Elevations in feet above mean sea level.

Approximate magnetic declination, 1972, for centre of map, 27° 10' west, decreasing 2.4' annually.

Fieldwork for this project was funded by the Government of Newfoundland and Labrador. Publication funded under the Canada/Newfoundland Mineral Development Subsidiary Agreement (1977-81), financed jointly by the Departments of Regional Economic Expansion (45%) and Energy, Mines and Resources (45%) of the Government of Canada and by the Government of Newfoundland and Labrador (10%).

Color separations and printing negatives by Maritime Resource Management Service, Amherst. Nova Scotia. 1982

60°
58°
56°
54°
52°
52°
52°
COAST OF LABRADOR
QUEBEC
Strait of Belle Isle
C. Bauld
ATLANTIC
OCEAN
50°
50°
GULF OF
ST. LAWRENCE
ISLAND
OF
NEWFOUNDLAND
Grand
L.
Gander
Bonavista
St. Georges B.
Trinity B.
48°
48°
C. Ray
Port aux Basques
Cabot Strait
ST. JOHN'S
NOVA
SCOTIA
Glace Bay
CAPE BRETON
ISLAND
Miquelon Is.
(France)
St. Pierre
C. Race
ATLANTIC
OCEAN
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46°
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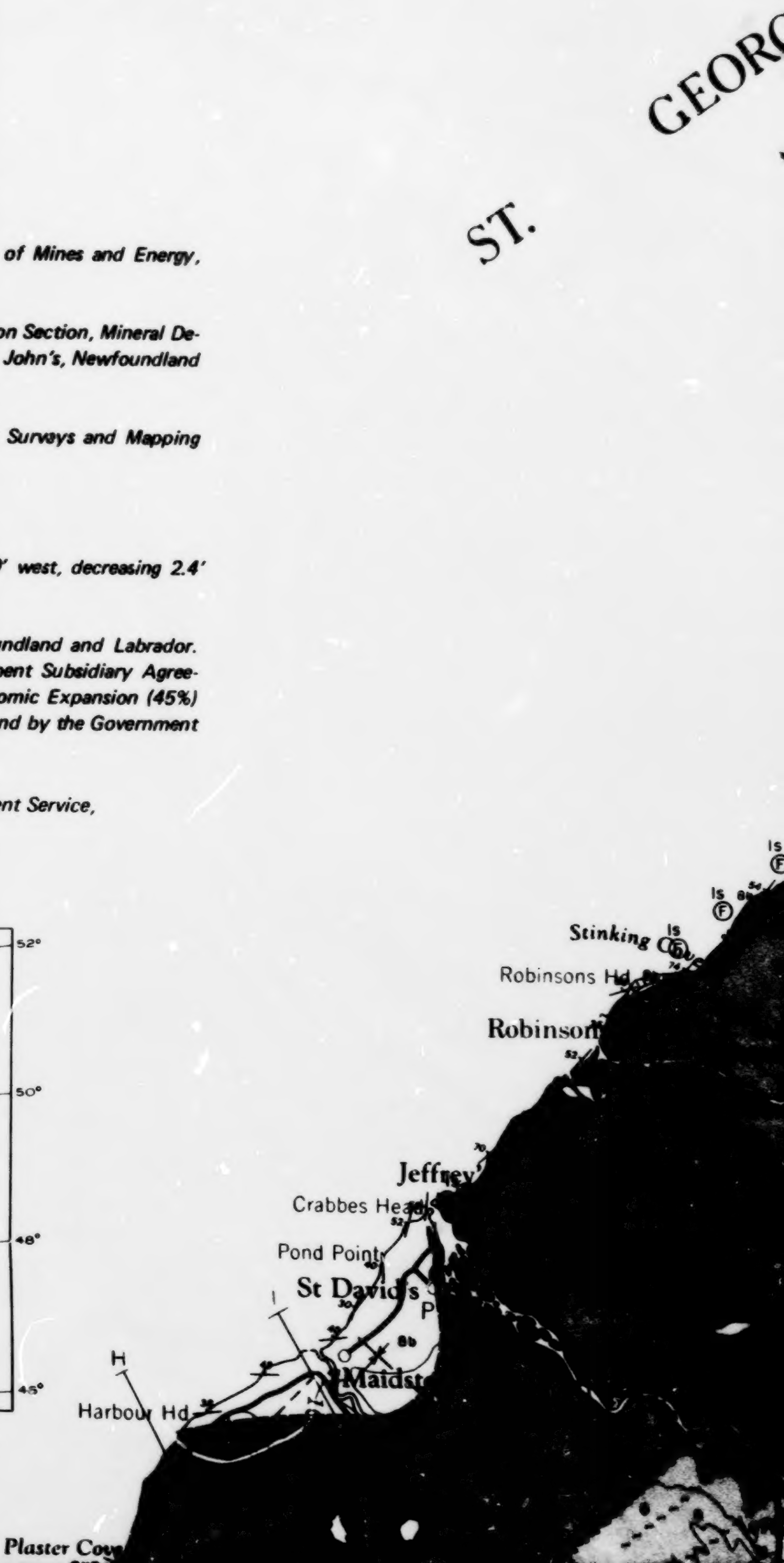
52°

INDEX MAP


ST. GEORG
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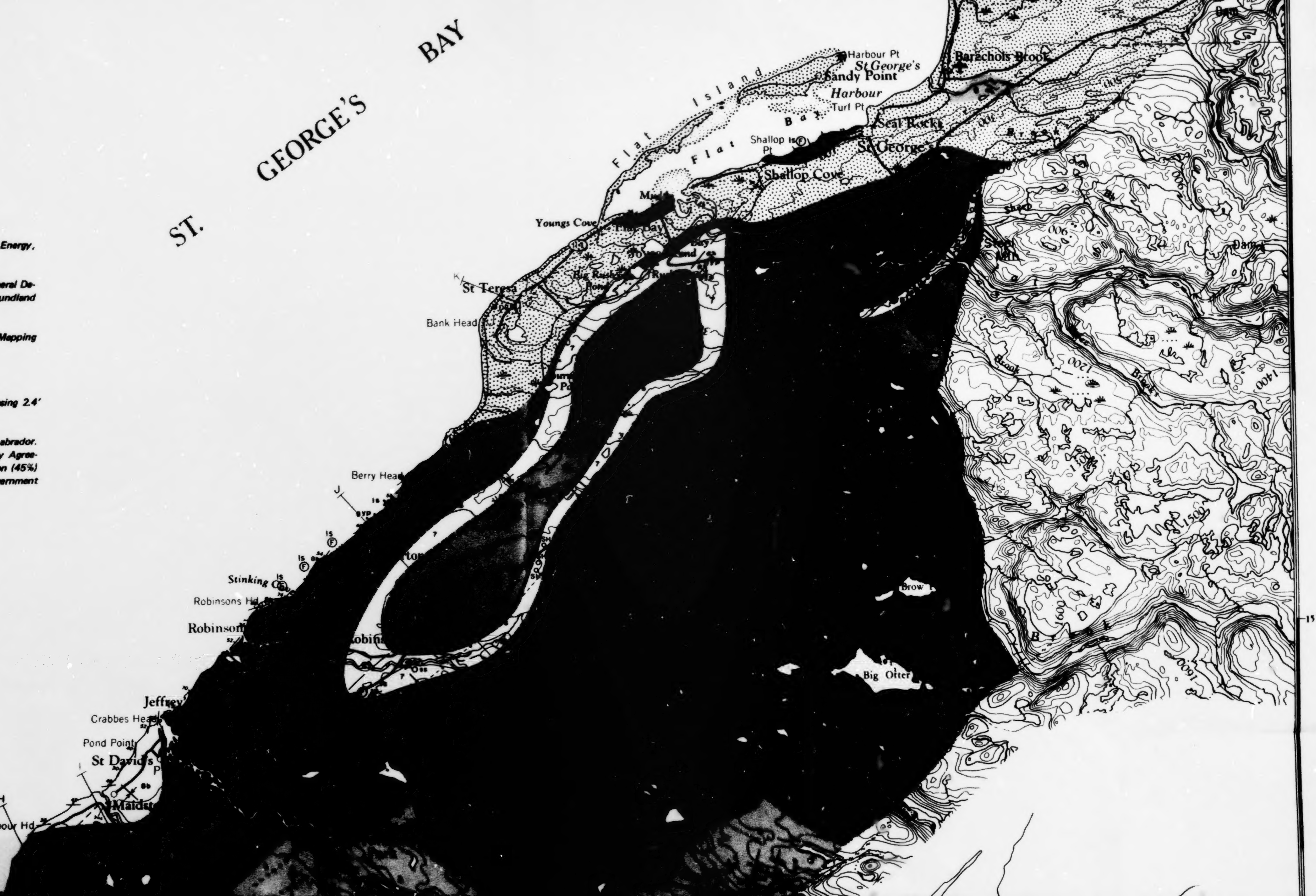

ST. GEORGE'S BAY
Flat Island
Harbour Pt
St George's
Sandy Point
Harbour
Turf Pt
Flat Bay
Shallop Is
Pt
Barachois Brook
Seal Rocks
St George's
Shallop Cove
Youngs Cove
Flat Bay
St Teresa
Bank Head
Big Rock
Berry Head
Stinking Co
Robinsons Hd
Robinson
Jeffrey
Crabbes Head
Pond Point
St David's
Maidst
Harbour Hd
Plaster Cove
Brow
Big Otter
Brook
1200
1400
1500
1600
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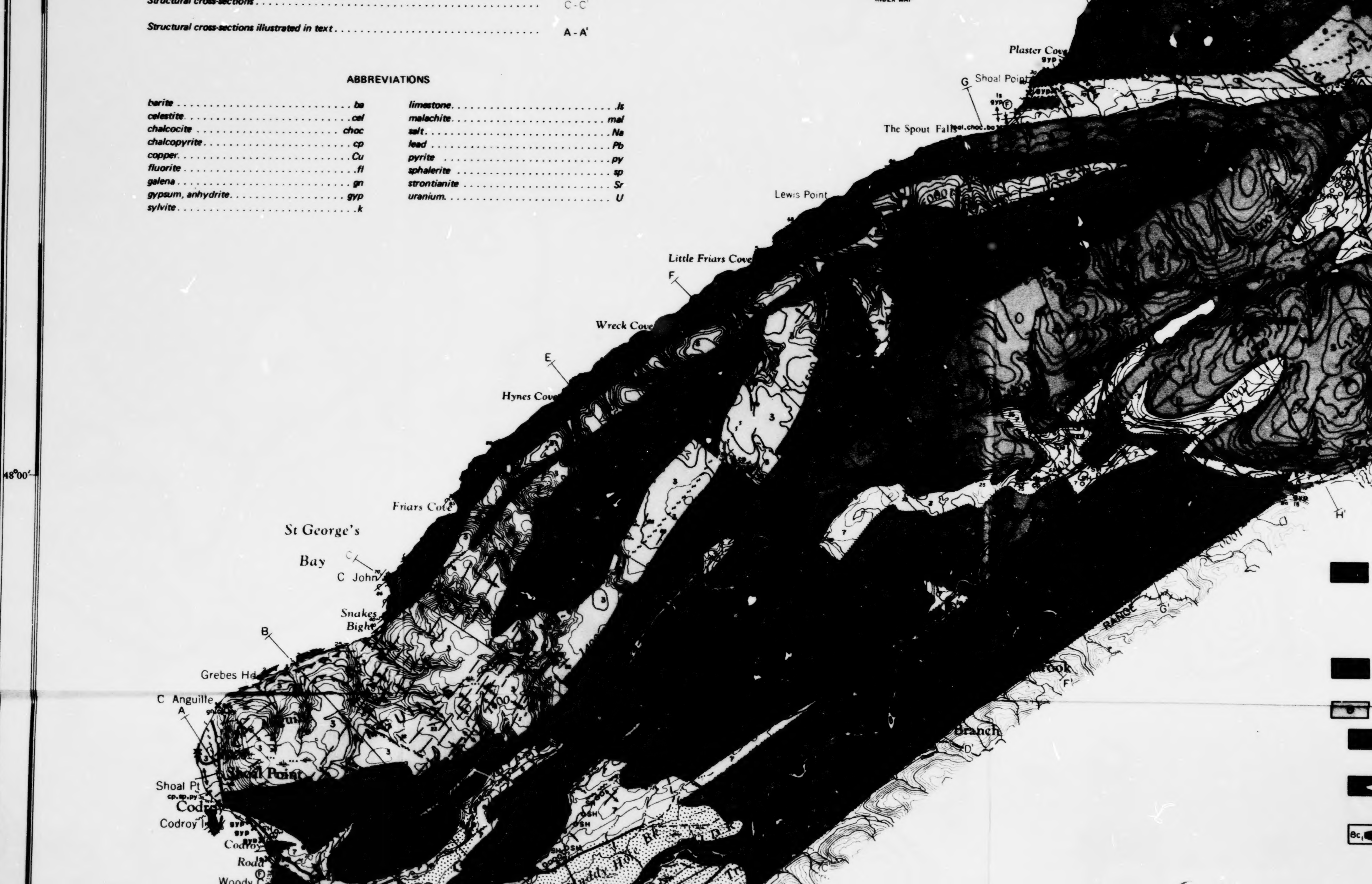
15′
H
I
J
K

Structural cross-sections . . . . C - C'

Structural cross-sections illustrated in text . . . . A - A'

ABBREVIATIONS

barite	*ba*	*limestone*	*ls*
celestite	*cel*	*malachite*	*mal*
chalcocite	*choc*	*salt*	*Na*
chalcopyrite	*cp*	*lead*	*Pb*
copper	*Cu*	*pyrite*	*py*
fluorite	*fl*	*sphalerite*	*sp*
galena	*gn*	*strontianite*	*Sr*
gypsum, anhydrite	*gyp*	*uranium*	*U*
sylvite	*k*		


INDEX MAP
Plaster Cove
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Shoal Point
ls
gyp
F
The Spout Falls
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Lewis Point
Little Friars Cove
F
Wreck Cove
E
Hynes Cove
48°00'
Friars Cove
St George's
Bay
C
C John
Snakes
Bight
B
Grebes Hd
C Anguille
A
Shoal Point
Shoal Pt
cp, sp, py
Codroy
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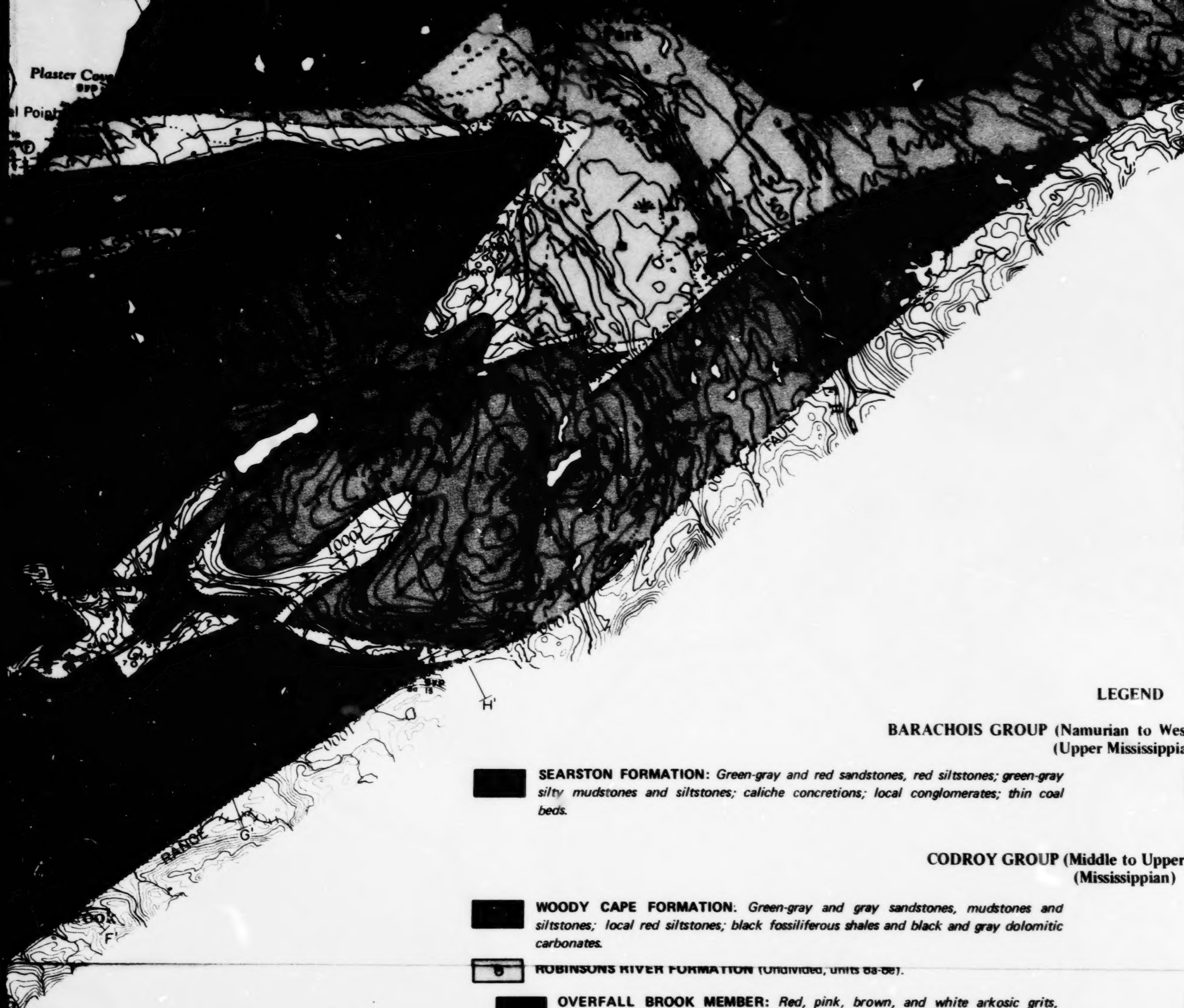
RANGE
Brook
F'
Branch
D'
D
Bc


Plaster Cove
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RANGE
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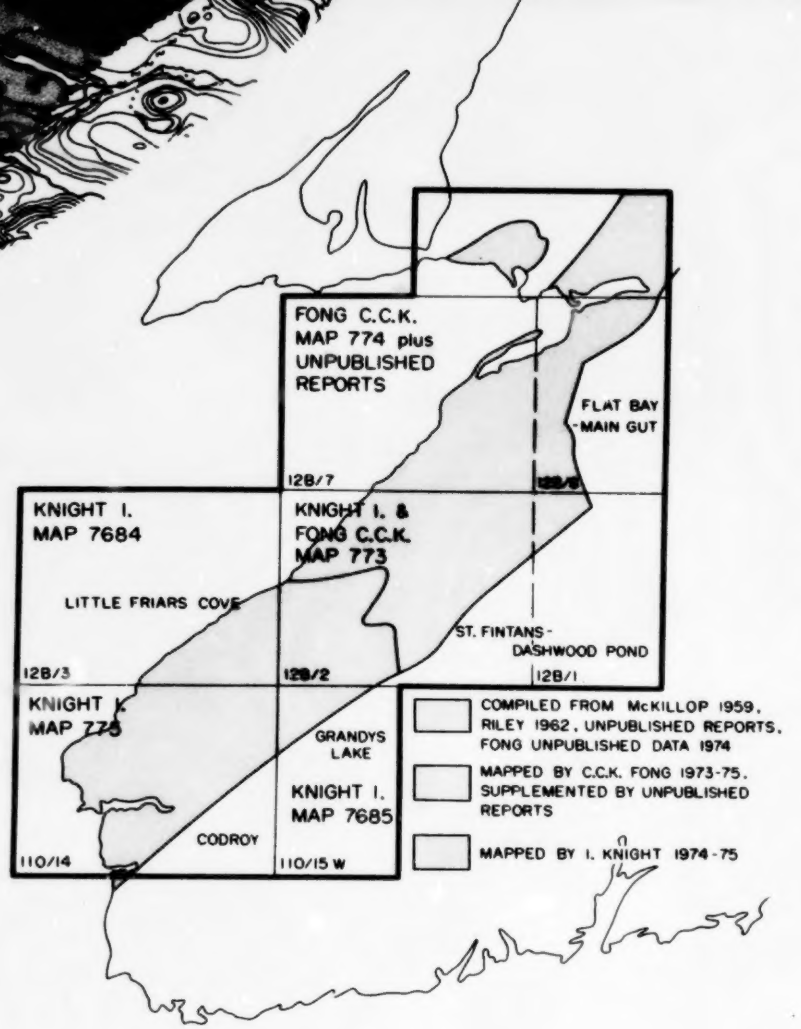

FONG C.C.K.
MAP 774 plus
UNPUBLISHED
REPORTS
FLAT BAY
-MAIN GUT
12B/7
12B/8
KNIGHT I.
MAP 7684
KNIGHT I. &
FONG C.C.K.
MAP 773
LITTLE FRIARS COVE
ST. FINTANS-
DASHWOOD POND
12B/3
12B/2
12B/1
KNIGHT I.
MAP 775
GRANDYS
LAKE
KNIGHT I.
MAP 7685
CODROY
110/14
110/15 W
COMPILED FROM McKILLOP 1959, RILEY 1962, UNPUBLISHED REPORTS, FONG UNPUBLISHED DATA 1974
MAPPED BY C.C.K. FONG 1973-75, SUPPLEMENTED BY UNPUBLISHED REPORTS
MAPPED BY I. KNIGHT 1974-75

LEGEND

BARACHOIS GROUP (Namurian to Westphalian A) (Units 10-11)
(Upper Mississippian to Pennsylvanian)

■ **SEARSTON FORMATION:** *Green-gray and red sandstones, red siltstones; green-gray silty mudstones and siltstones; caliche concretions; local conglomerates; thin coal beds.*

■ **UNDIVIDED BARACHOIS GROUP:** *Green-gray and red sandstones, pebbly sandstones, red siltstones; dark gray to black shales and mudstones; coal beds.*

CODROY GROUP (Middle to Upper Visean) (Units 6-9)
(Mississippian)

■ **WOODY CAPE FORMATION:** *Green-gray and gray sandstones, mudstones and siltstones; local red siltstones; black fossiliferous shales and black and gray dolomitic carbonates.*

8 **ROBINSONS RIVER FORMATION** (Undivided, units 8a-8e).

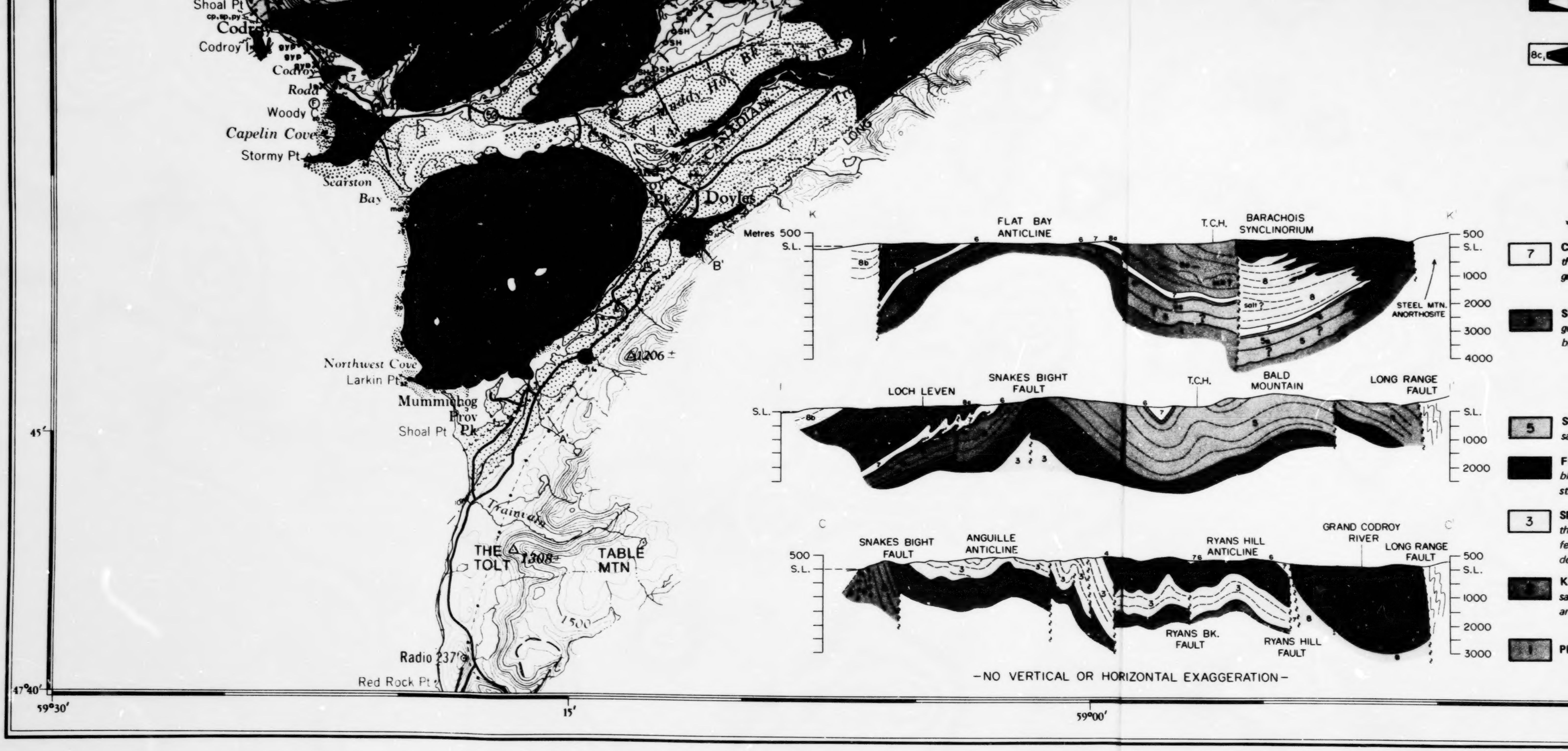
■ **OVERFALL BROOK MEMBER:** *Red, pink, brown, and white arkosic grits, sandstones and some conglomerates; some gray siltstones and sandstones; some red siltstones.*

■ **MOLLICHIGNICK MEMBER:** *Red siltstones and sandstones, gray sandstones, shales, mudstones, and siltstones; white marine sandstones, silty carbonates, dolomites and limestones, fossiliferous; caliche limestones. Sandstones predominantly micaceous.*

8c$_1$ *Brown, red and gray, arkosic and muddy, pebbly sandstones and conglomerates.*

■ **BROW POND LENTIL:** *Pink and red, pebbly and cobbly arkosic grits and sandstones.*

8b **HIGHLANDS MEMBER:** *Predominantly thick, red, with some gray and yellow sandstones (locally pebbly) and intercalated thick red siltstones with thin red sandstones;*


Shoal Pt
Codroy
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Codroy
Rodd
Woody C
Capelin Cove
Stormy Pt
Searston Bay
Northwest Cove
Larkin Pt
Mummichog Prov Pk
Shoal Pt
Doyles
B'
CANADIAN
LONG
1206 ±
Traintaln
THE TOLT
1308±
TABLE MTN
1500
Radio 237
Red Rock Pt
45'
47°40'
59°30'
15'
59°00'
K
K'
Metres 500
S.L.
FLAT BAY ANTICLINE
T.C.H.
BARACHOIS SYNCLINORIUM
STEEL MTN. ANORTHOSITE
salt ?
500
S.L.
1000
2000
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4000
I
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LOCH LEVEN
SNAKES BIGHT FAULT
T.C.H.
BALD MOUNTAIN
LONG RANGE FAULT
S.L.
1000
2000
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C'
SNAKES BIGHT FAULT
ANGUILLE ANTICLINE
RYANS HILL ANTICLINE
GRAND CODROY RIVER
LONG RANGE FAULT
RYANS BK. FAULT
RYANS HILL FAULT
500
S.L.
1000
2000
3000
8b
8a
8c
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6
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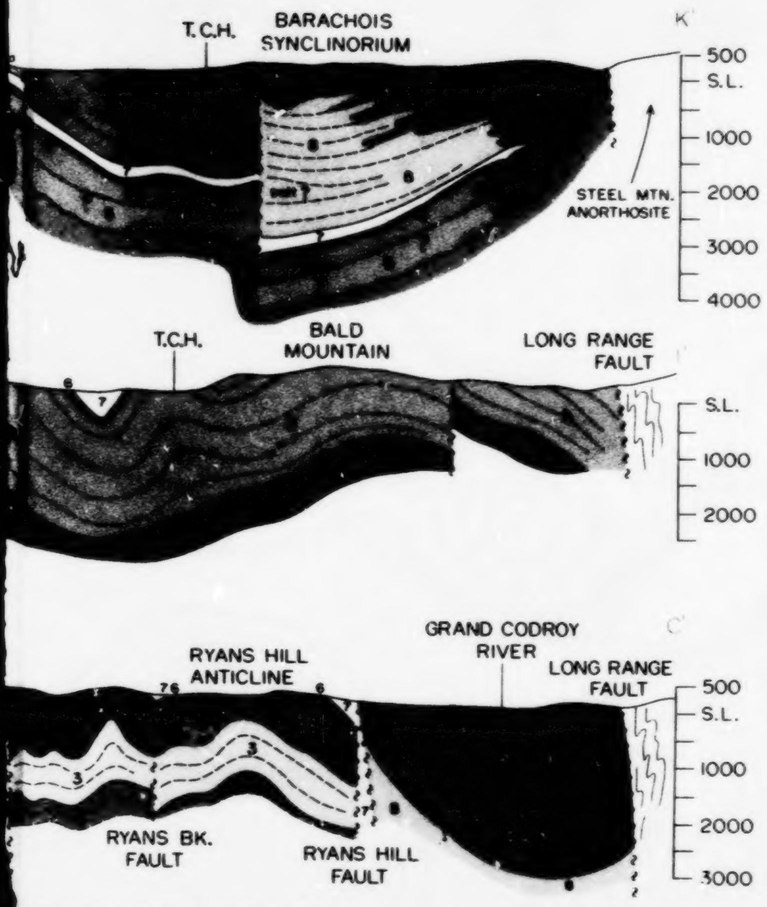
1

-NO VERTICAL OR HORIZONTAL EXAGGERATION-shales, mudstones, and siltstones; white marine sandstones, silty carbonates, dolomites and limestones, fossiliferous; caliche limestones. Sandstones predominantly micaceous.

8c₁ *Brown, red and gray, arkosic and muddy, pebbly sandstones and conglomerates.*

8b **HIGHLANDS MEMBER:** *Predominantly thick, red, with some gray and yellow sandstones (locally pebbly) and intercalated thick red siltstones with thin red sandstones; caliche limestones and some caliche conglomerates. Two units of limestones and gray to white sandstones and siltstones (possibly marine).*

▨ **JEFFREYS VILLAGE MEMBER:** *Predominantly red siltstones with thin red sandstones; thick red and locally gray sandstones, locally pebbly in the north; brown, red and gray conglomerates; caliche limestones; gray shales, siltstones and sandstones, fossilferous; red, gray, green and black halite bearing marls, mudstones, and siltstones; gray, algal, oolitic and fossiliferous, silty limestones, dolomitic limestones and dolomites, red dolomites; white gypsum anhydrite and salt in subsurface.*



RIZONTAL EXAGGERATION –

7 **CODROY ROAD FORMATION:** *Red, green and gray siltstones and mudstones, some thin red sandstones; black dolomites, locally highly, fossiliferous; white gypsum and gray anhydrite with gray shales and dolomite laminae.*

6 **SHIP COVE FORMATION:** *Laminated gray limestones and silty and shaly limestones; gray shales, green and red siltstones and shales locally; gray sandstones and intraclastic breccia locally; locally fossiliferous; gypsum molds and fenestra common.*

ANGUILLE GROUP (Tournaisian) (Units 2-5, 5a)
(Mississippian, may include Upper Devonian?)

5 **SPOUT FALLS FORMATION:** *Red and gray sandstones, pebbly and intraclastic sandstones, minor siltstones; minor conglomerates in the north.*

5a **FISCHELLS CONGLOMERATE MEMBER:** *Thickly bedded gray, cobble and pebble conglomerates and sandstones.*

▨ **FRIARS COVE FORMATION:** *Gray sandstones, siltstones, and mudstones, gray and black shales; locally red beds; minor dolomitic limestones and dolomites, some stromatolites; basal gray sandstone and conglomerate member.*

3 **SNAKES BIGHT FORMATION:** *Black shales and thin sandstones at base; bedded and thick units of gray sandstones, black shales and siliceous shales; thin gray siltstones; ferruginous dolomite laminae and beds, minor sandy limestones; lenses of quartz and dolomite pebble conglomerates.*

▨ **KENNELS BROOK FORMATION:** (Probably Upper Devonian age) *Green-gray and red sandstones and pebbly sandstones, red siltstones; interbedded gray and brown siltstones and mudstones with gray limestone at top. Base not exposed.*

▨ **PRE–CARBONIFEROUS BASEMENT within subbasin.**

Published 1982

45'

47°40'

45'

30'

58°15'

FOLDOUT A

FIGURE 5
SNAKES BIGHT FORMATION
TYPE SECTION,
HYNES GULCH

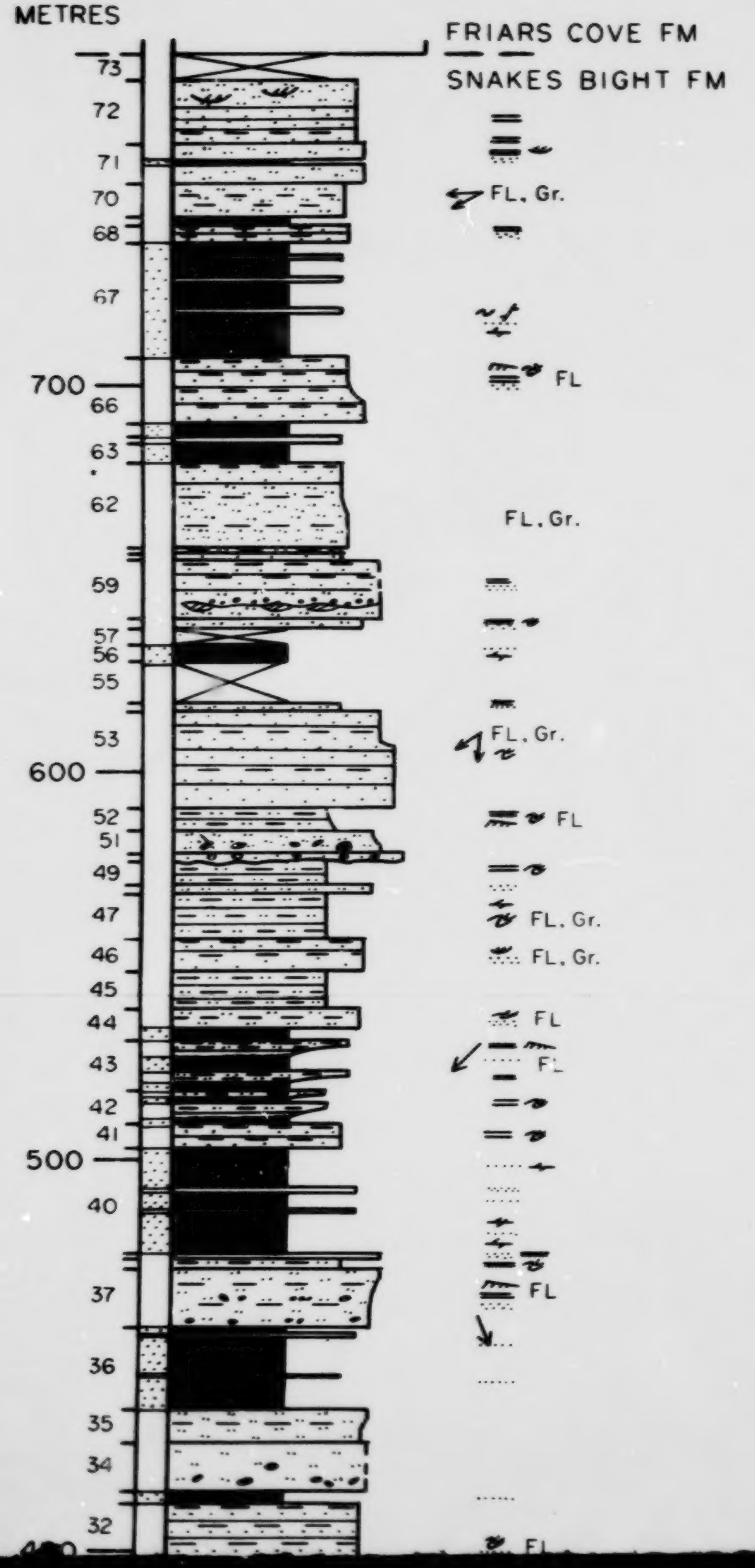
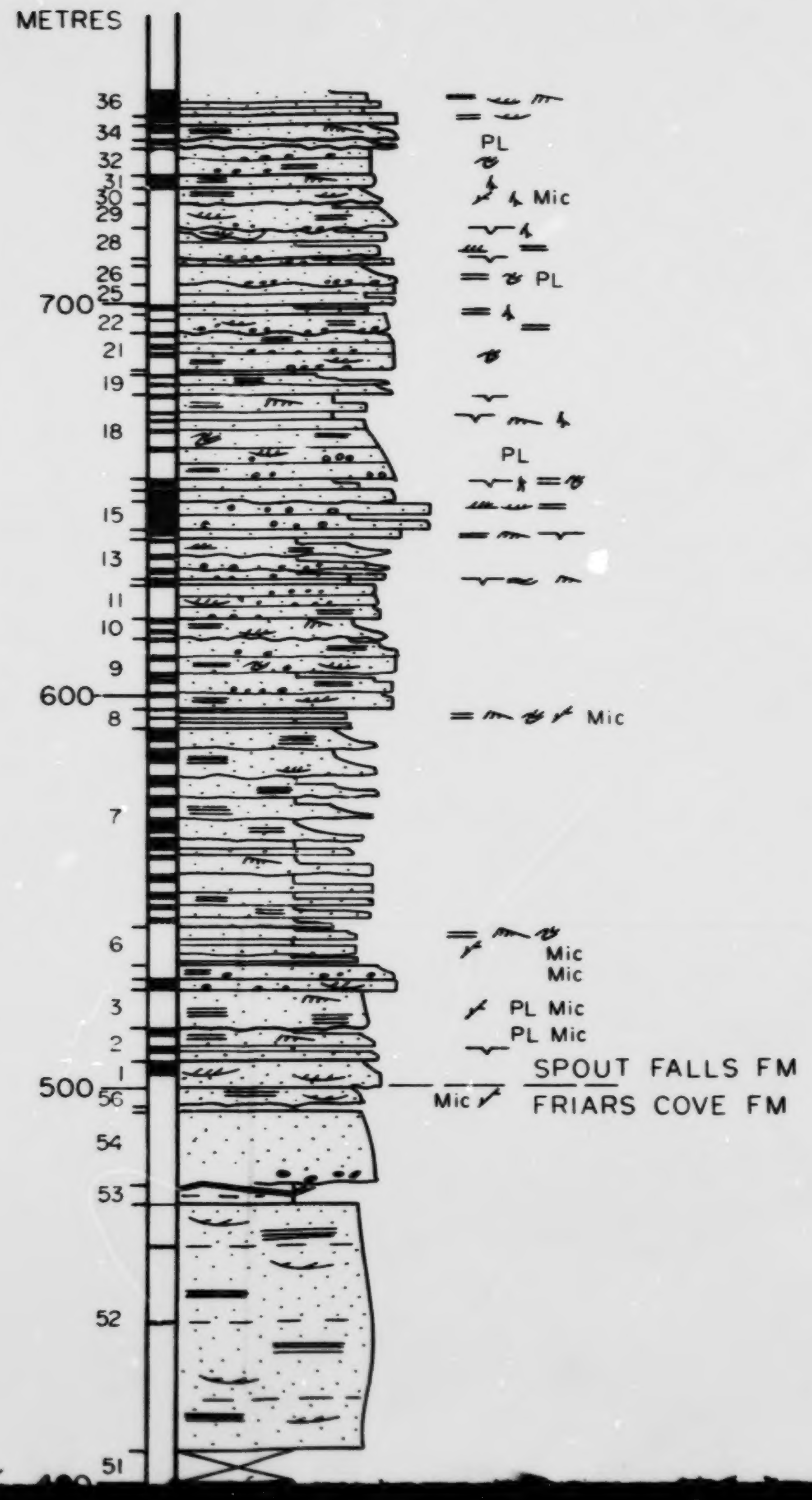
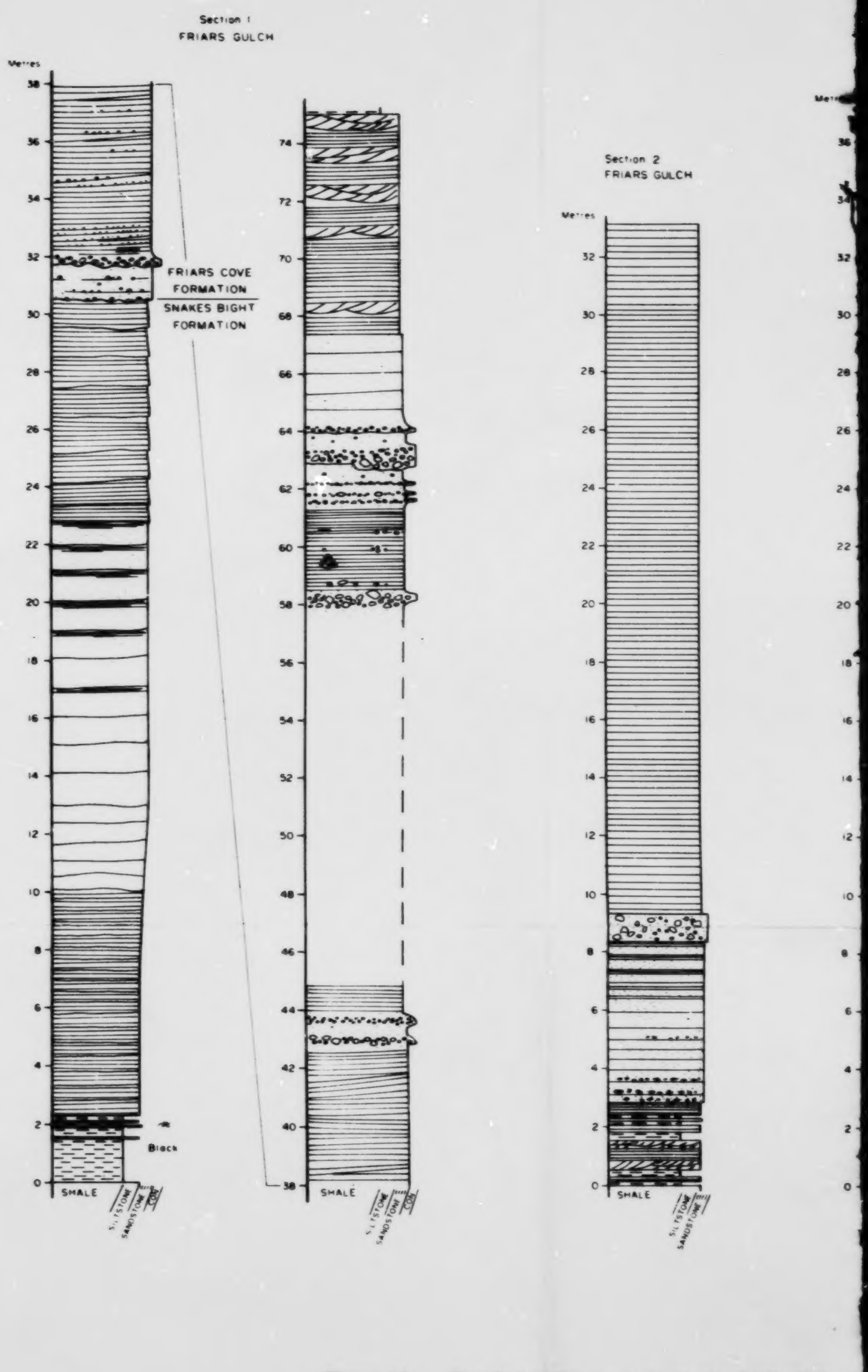

METRES
FRIARS COVE FM
SNAKES BIGHT FM
700
600
500
FL, Gr.
FL
Mic

FIGURE 8
SPOUT FALLS FORMATION
AND
FRIARS COVE FORMATION
TYPE SECTION
NORTH SHORE OF
FRIARS COVE
AND
FRIARS GULCH


METRES
700
600
500
PL
Mic
SPOUT FALLS FM
FRIARS COVE FM


Section 1
FRIARS GULCH
Metres
FRIARS COVE FORMATION
SNAKES BIGHT FORMATION
Black
SHALE
SILTSTONE
SANDSTONE
Section 2
FRIARS GULCH

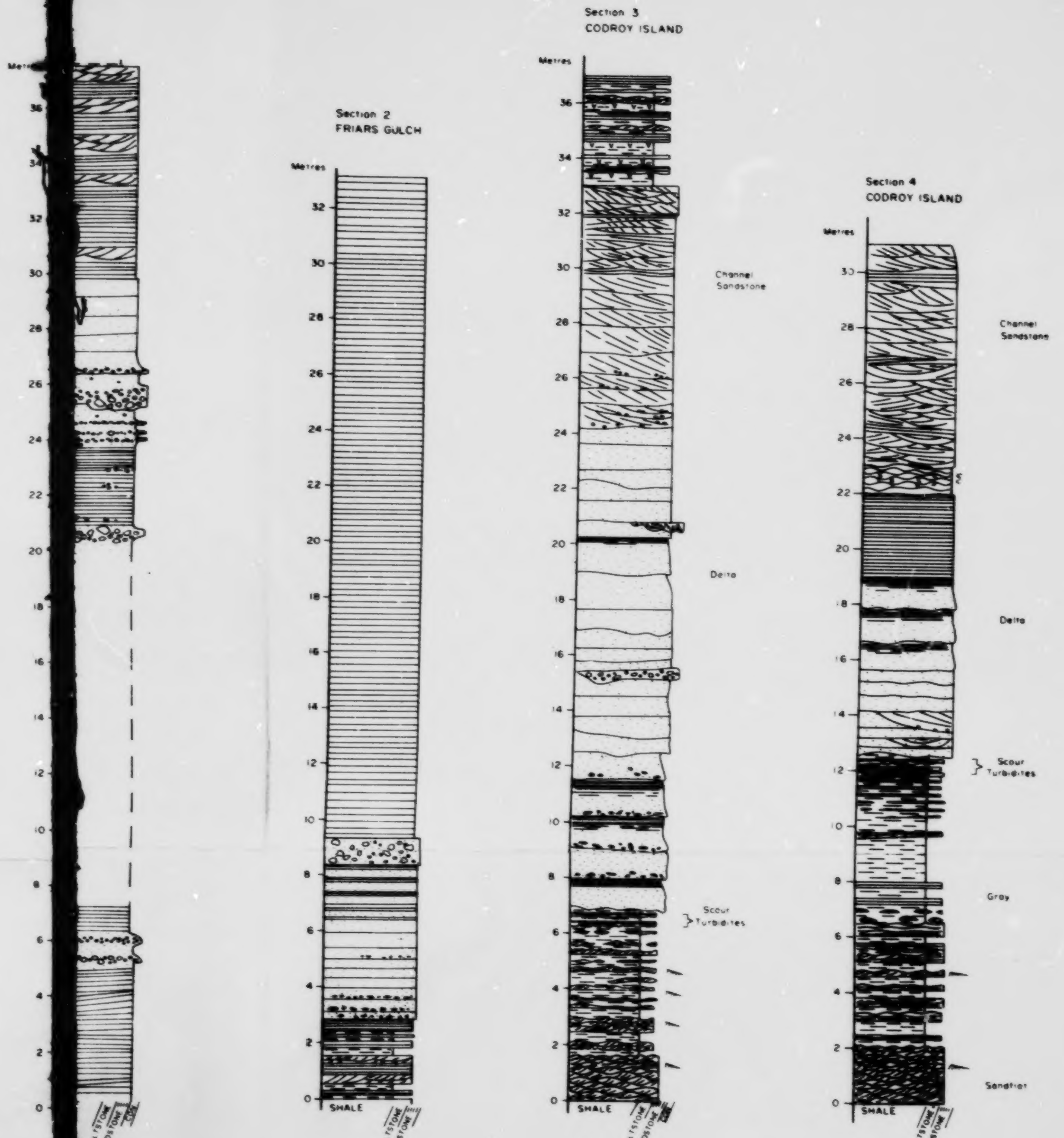
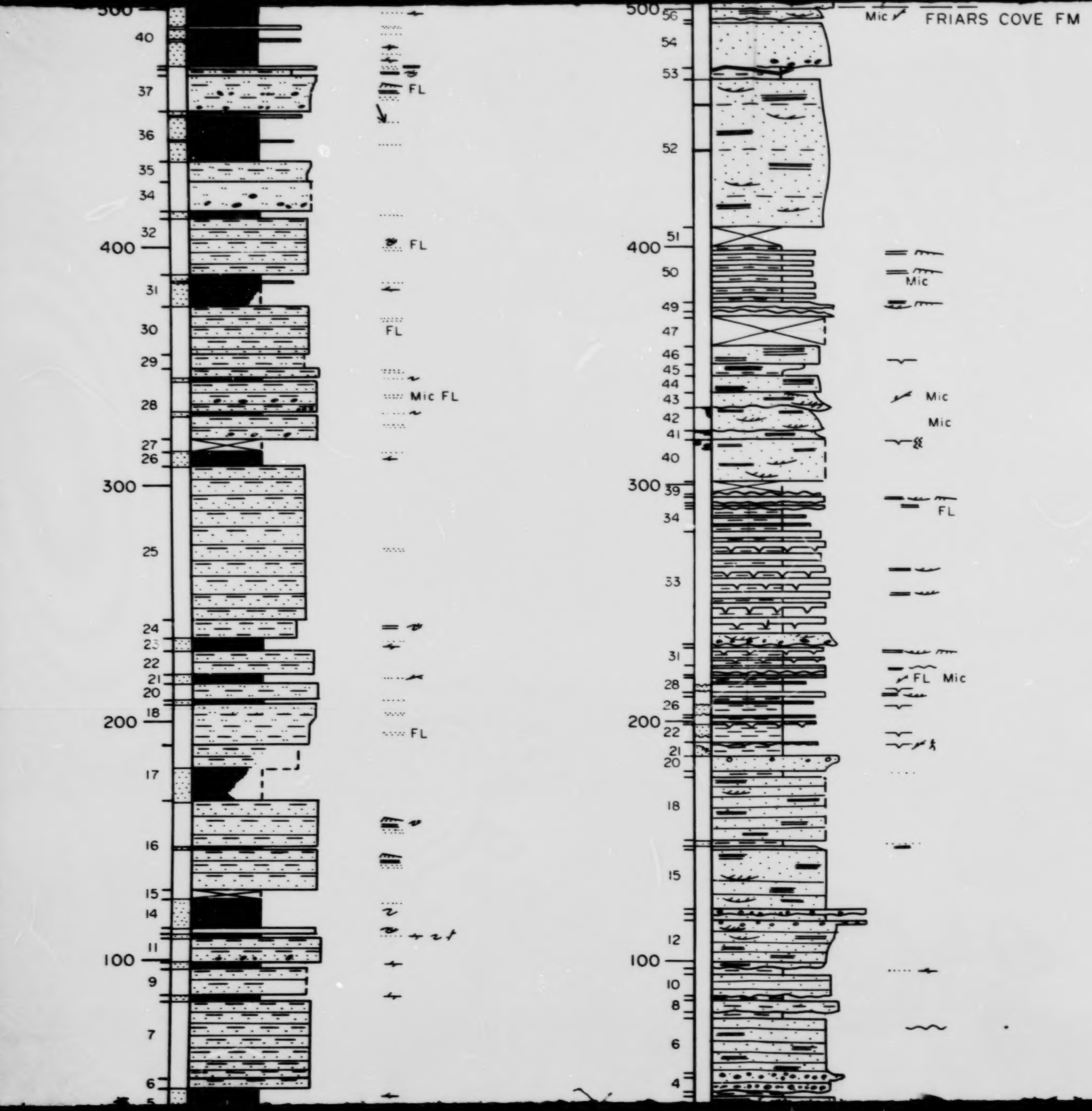

Section 2
FRIARS GULCH
Section 3
CODROY ISLAND
Section 4
CODROY ISLAND
Metres
Channel Sandstone
Delta
Scour Turbidites
Grey
Sandflat
SHALE
SILTSTONE
SANDSTONE

Figure 11: Detailed sedimentary sections of lithofacies i on Friars Gulch and Codroy Island.

re 11: Detailed sedimentary sections of lithofacies in the Friars Cove Formation. Sections located on Friars Gulch and Codroy Island.


FRIARS COVE FM
500
400
300
200
100
Mic
FL
Mic FL

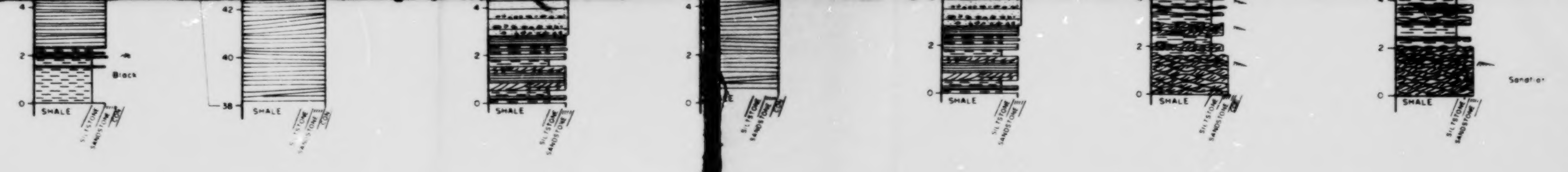
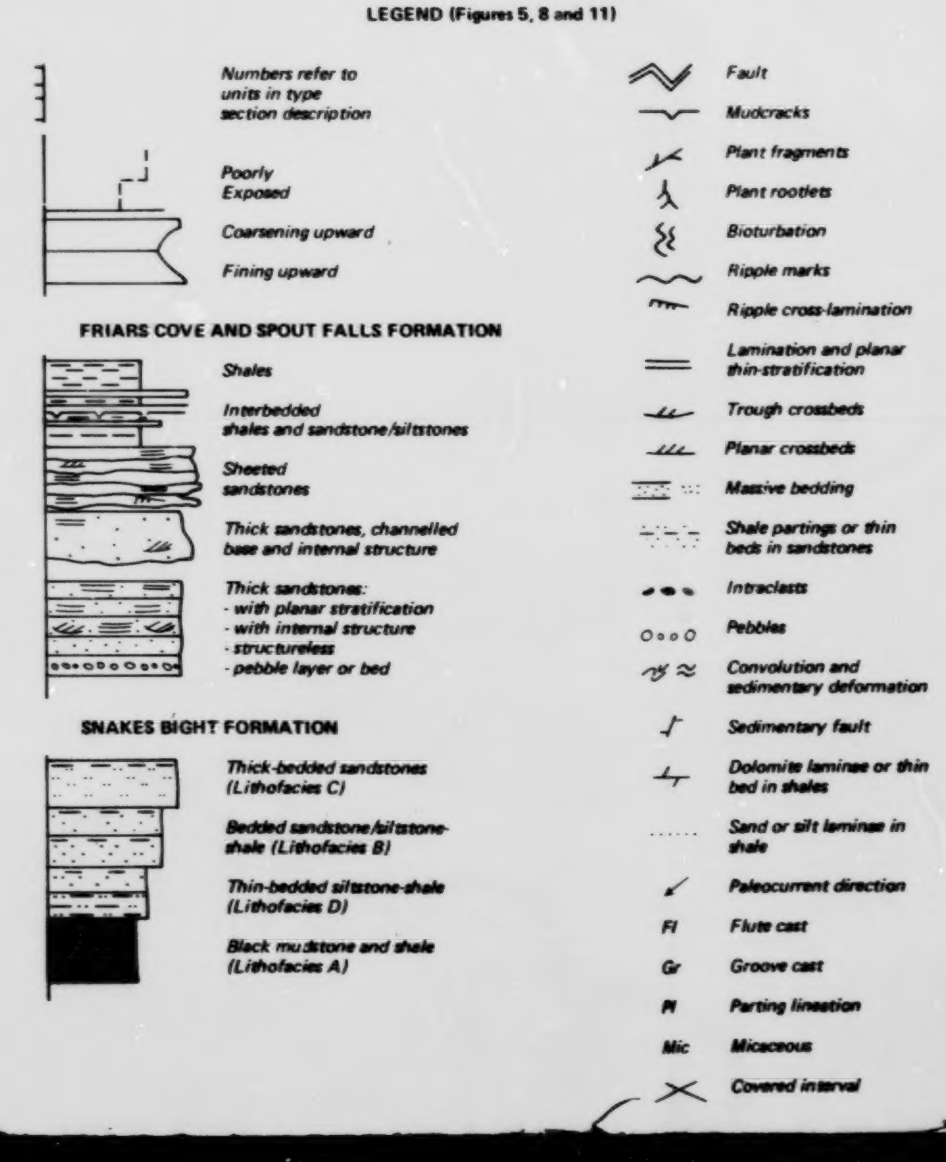
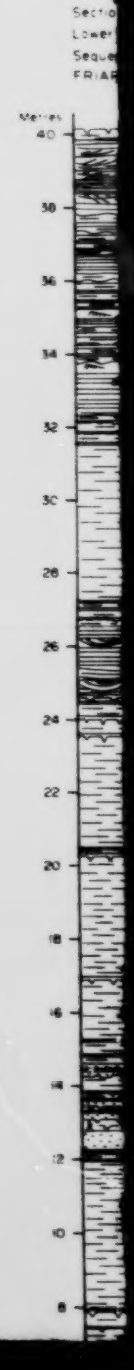
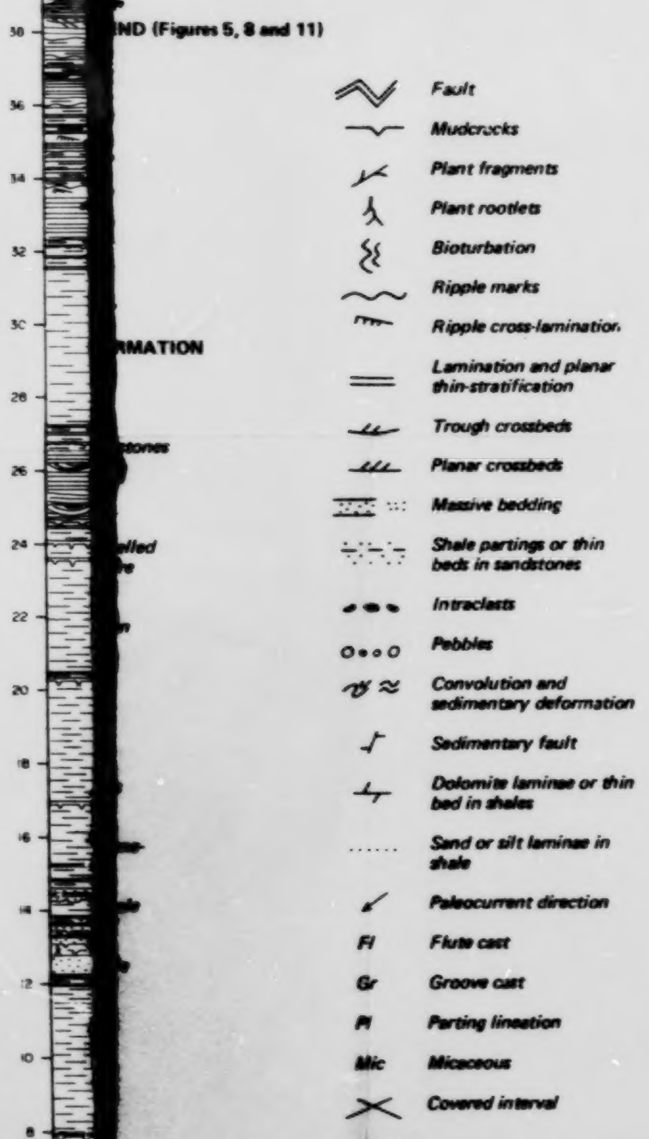

SHALE
SILTSTONE
SANDSTONE
Black
Sanstone

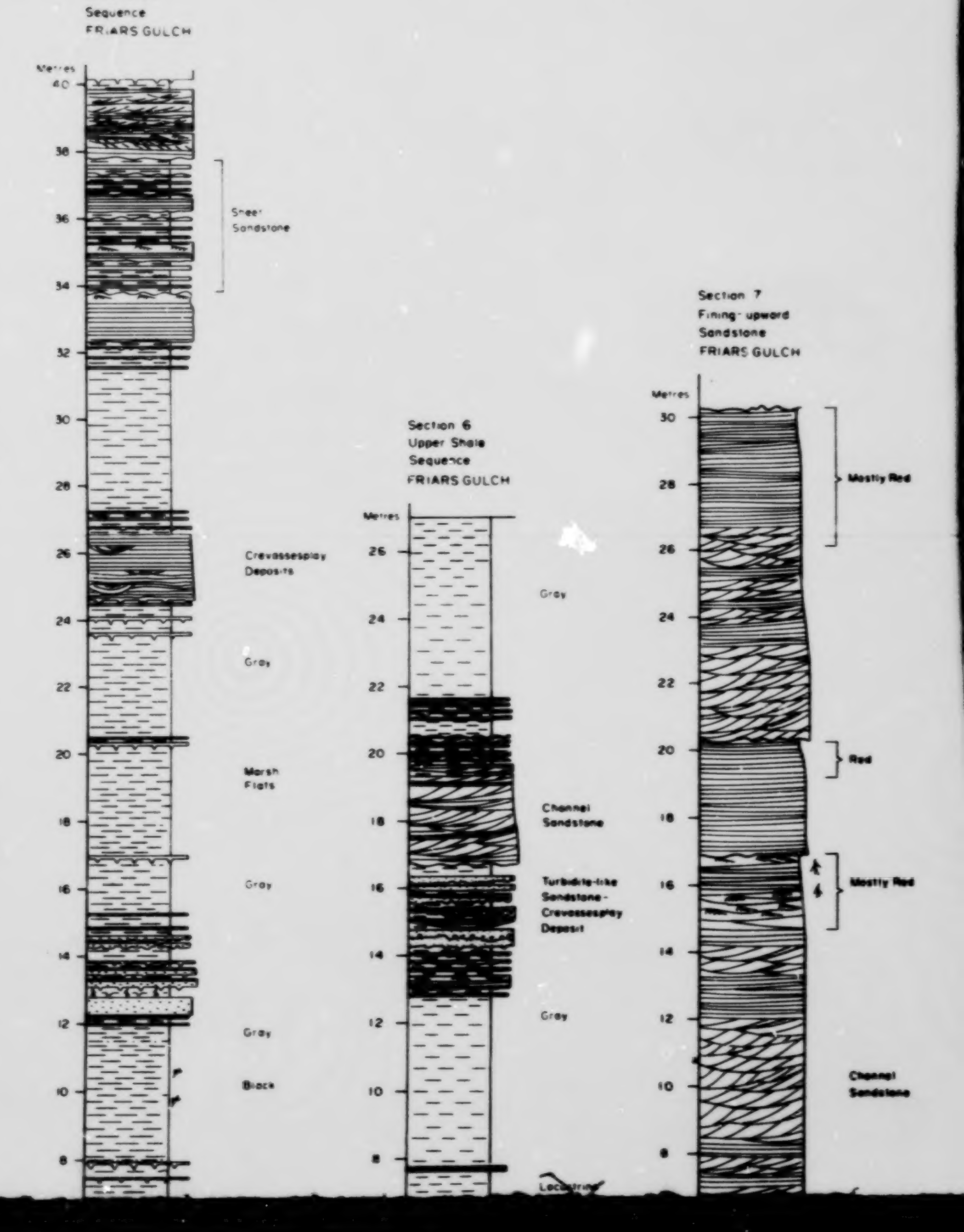
Figure 11: Detailed sedimentary sections of lithofacies in on Friars Gulch and Codroy Island.

Figure 11: Detailed sedimentary sections of lithofacies in the Friars Cove Formation. Sections located on Friars Gulch and Codroy Island.


LEGEND (Figures 5, 8 and 11)
Numbers refer to units in type section description
Poorly Exposed
Coarsening upward
Fining upward
FRIARS COVE AND SPOUT FALLS FORMATION
Shales
Interbedded shales and sandstone/siltstones
Sheeted sandstones
Thick sandstones, channelled base and internal structure
Thick sandstones: - with planar stratification - with internal structure - structureless - pebble layer or bed
SNAKES BIGHT FORMATION
Thick-bedded sandstones (Lithofacies C)
Bedded sandstone/siltstone-shale (Lithofacies B)
Thin-bedded siltstone-shale (Lithofacies D)
Black mudstone and shale (Lithofacies A)
Fault
Mudcracks
Plant fragments
Plant rootlets
Bioturbation
Ripple marks
Ripple cross-lamination
Lamination and planar thin-stratification
Trough crossbeds
Planar crossbeds
Massive bedding
Shale partings or thin beds in sandstones
Intraclasts
Pebbles
Convolution and sedimentary deformation
Sedimentary fault
Dolomite laminae or thin bed in shales
Sand or silt laminae in shale
Paleocurrent direction
Fl Flute cast
Gr Groove cast
Pl Parting lineation
Mic Micaceous
Covered interval


Section
Lower
Seque
FRIAR
Metres


ND (Figures 5, 8 and 11)
RMATION
Fault
Mudcracks
Plant fragments
Plant rootlets
Bioturbation
Ripple marks
Ripple cross-lamination
Lamination and planar thin-stratification
Trough crossbeds
Planar crossbeds
Massive bedding
Shale partings or thin beds in sandstones
Intraclasts
Pebbles
Convolution and sedimentary deformation
Sedimentary fault
Dolomite laminae or thin bed in shales
Sand or silt laminae in shale
Paleocurrent direction
Fl Flute cast
Gr Groove cast
Pl Parting lineation
Mic Micaceous
Covered interval


Section 5
Lower Shale Sequence
FRIARS GULCH
Metres
Sheet Sandstone
Crevassesplay Deposits
Gray
Marsh Flats
Gray
Gray
Black
Section 6
Upper Shale Sequence
FRIARS GULCH
Gray
Channel Sandstone
Turbidite-like Sandstone - Crevassesplay Deposit
Gray
Lacustrine
Section 7
Fining-upward Sandstone
FRIARS GULCH
Mostly Red
Red
Mostly Red
Channel Sandstone

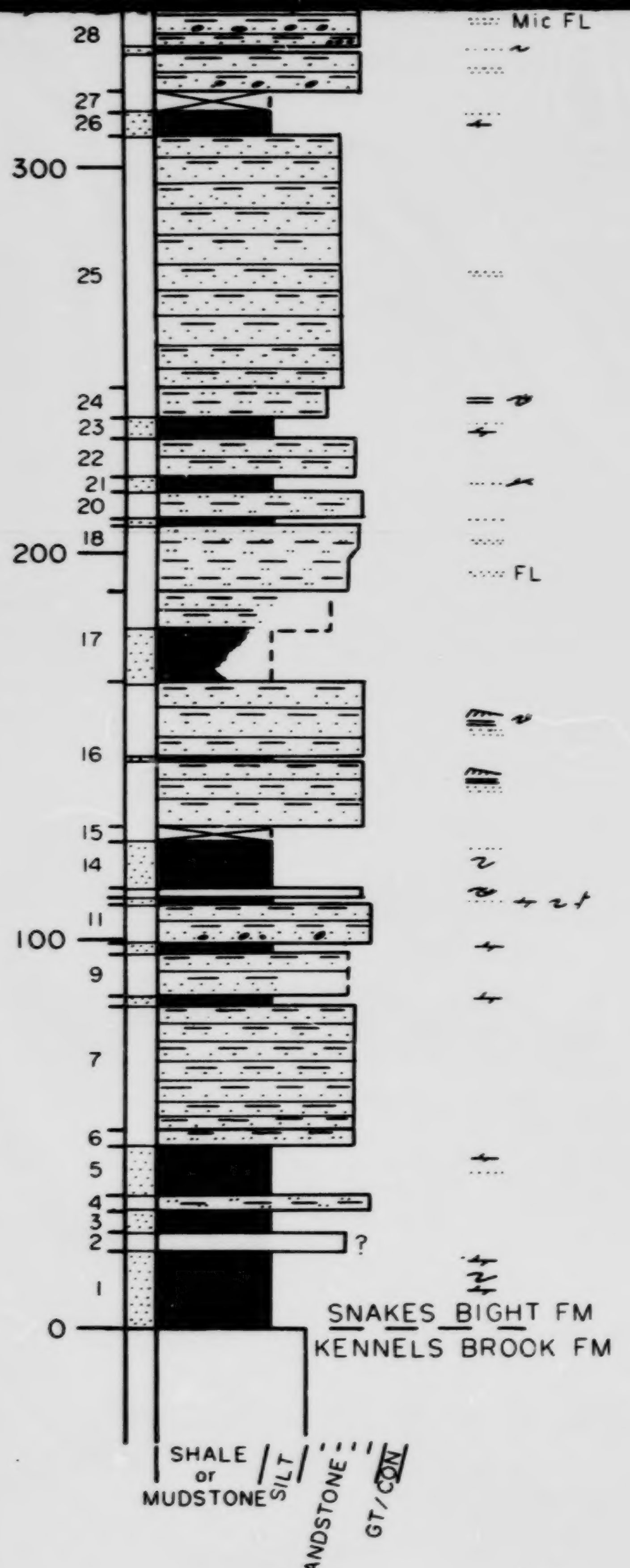

Mic FL
28
27
26
300
25
24
23
22
21
20
18
200
FL
17
16
15
14
11
100
9
7
6
5
4
3
2
?
1
0
SNAKES BIGHT FM
KENNELS BROOK FM
SHALE or MUDSTONE
SILT
SANDSTONE
GT/CON

Figure 5: Type section of the Snakes Bight Formation in Hynes Gulch.

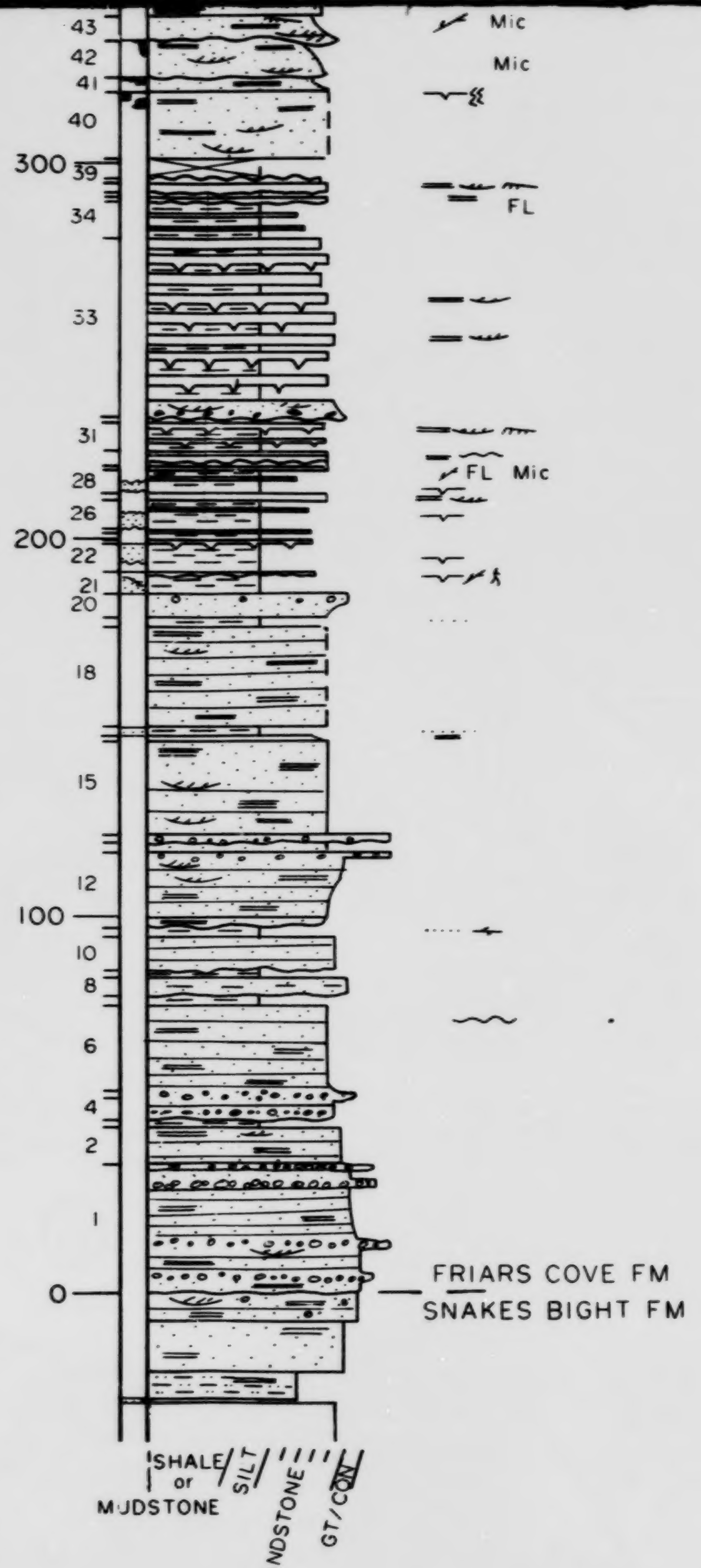
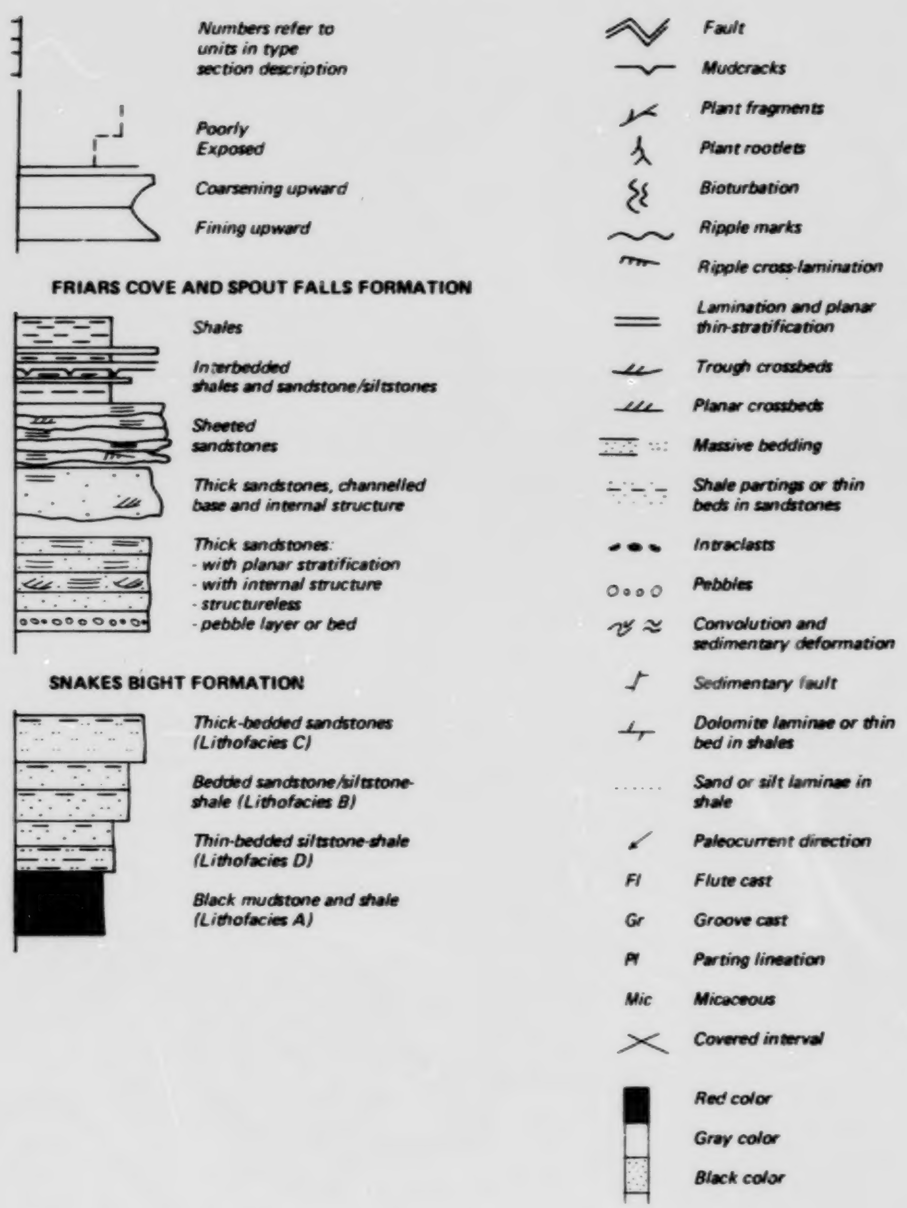
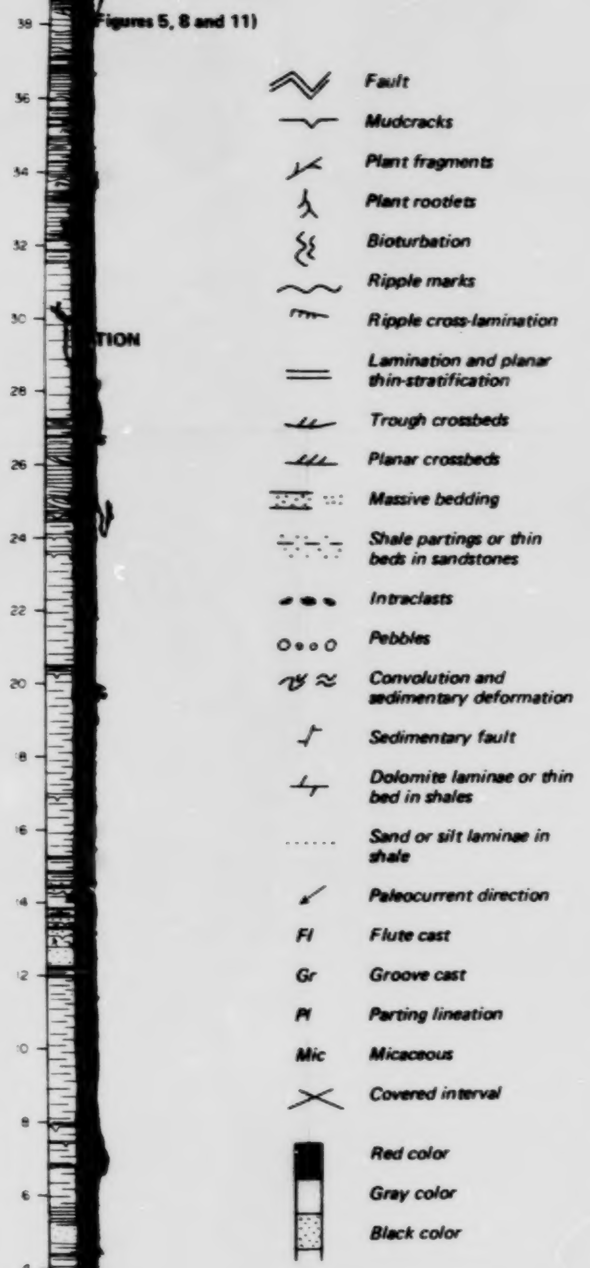

43
42
41
40
Mic
Mic
300
39
34
FL
33
31
28
26
22
21
20
200
FL Mic
18
15
12
100
10
8
6
4
2
1
0
FRIARS COVE FM
SNAKES BIGHT FM
SHALE or MUDSTONE
SILT
SANDSTONE
GT/CON

Figure 8: Type section of the Friars Cove Formation, Friars Gulch. Figure also illustrates incomplete section in the basal part of the Spout Falls Formation. The Spout Falls Formation was measured along the north shore of Friars Cove.

LEGEND (Figures 5, 8 and 11)


Numbers refer to units in type section description
Poorly Exposed
Coarsening upward
Fining upward
FRIARS COVE AND SPOUT FALLS FORMATION
Shales
Interbedded shales and sandstone/siltstones
Sheeted sandstones
Thick sandstones, channelled base and internal structure
Thick sandstones: - with planar stratification - with internal structure - structureless - pebble layer or bed
SNAKES BIGHT FORMATION
Thick-bedded sandstones (Lithofacies C)
Bedded sandstone/siltstone-shale (Lithofacies B)
Thin-bedded siltstone-shale (Lithofacies D)
Black mudstone and shale (Lithofacies A)
Fault
Mudcracks
Plant fragments
Plant rootlets
Bioturbation
Ripple marks
Ripple cross-lamination
Lamination and planar thin-stratification
Trough crossbeds
Planar crossbeds
Massive bedding
Shale partings or thin beds in sandstones
Intraclasts
Pebbles
Convolution and sedimentary deformation
Sedimentary fault
Dolomite laminae or thin bed in shales
Sand or silt laminae in shale
Paleocurrent direction
Fl Flute cast
Gr Groove cast
Pl Parting lineation
Mic Micaceous
Covered interval
Red color
Gray color
Black color

Metres
40
30
20
10
0


(Figures 5, 8 and 11)
Fault
Mudcracks
Plant fragments
Plant rootlets
Bioturbation
Ripple marks
Ripple cross-lamination
Lamination and planar thin-stratification
Trough crossbeds
Planar crossbeds
Massive bedding
Shale partings or thin beds in sandstones
Intraclasts
Pebbles
Convolution and sedimentary deformation
Sedimentary fault
Dolomite laminae or thin bed in shales
Sand or silt laminae in shale
Paleocurrent direction
Fl Flute cast
Gr Groove cast
Pl Parting lineation
Mic Micaceous
Covered interval
Red color
Gray color
Black color

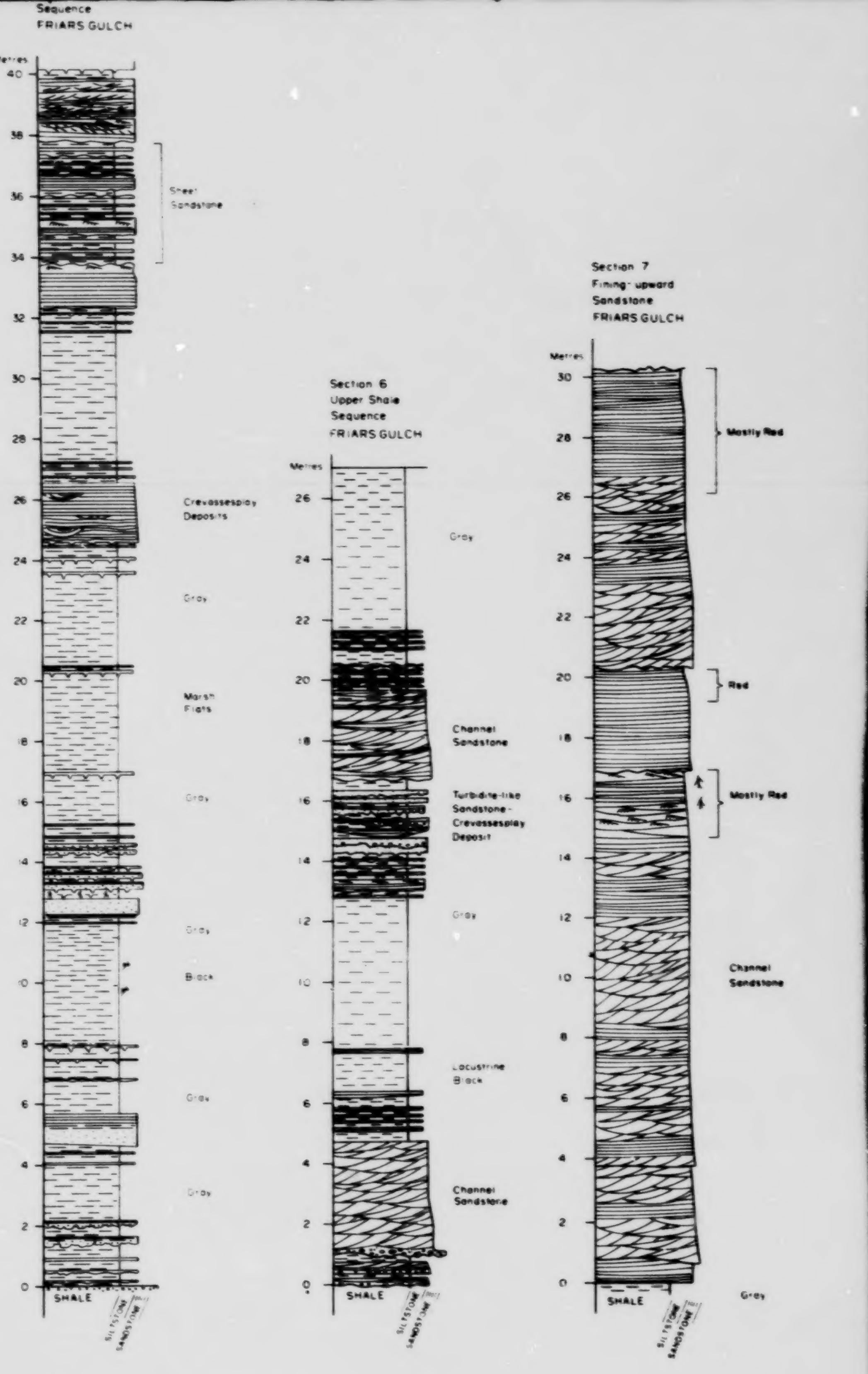
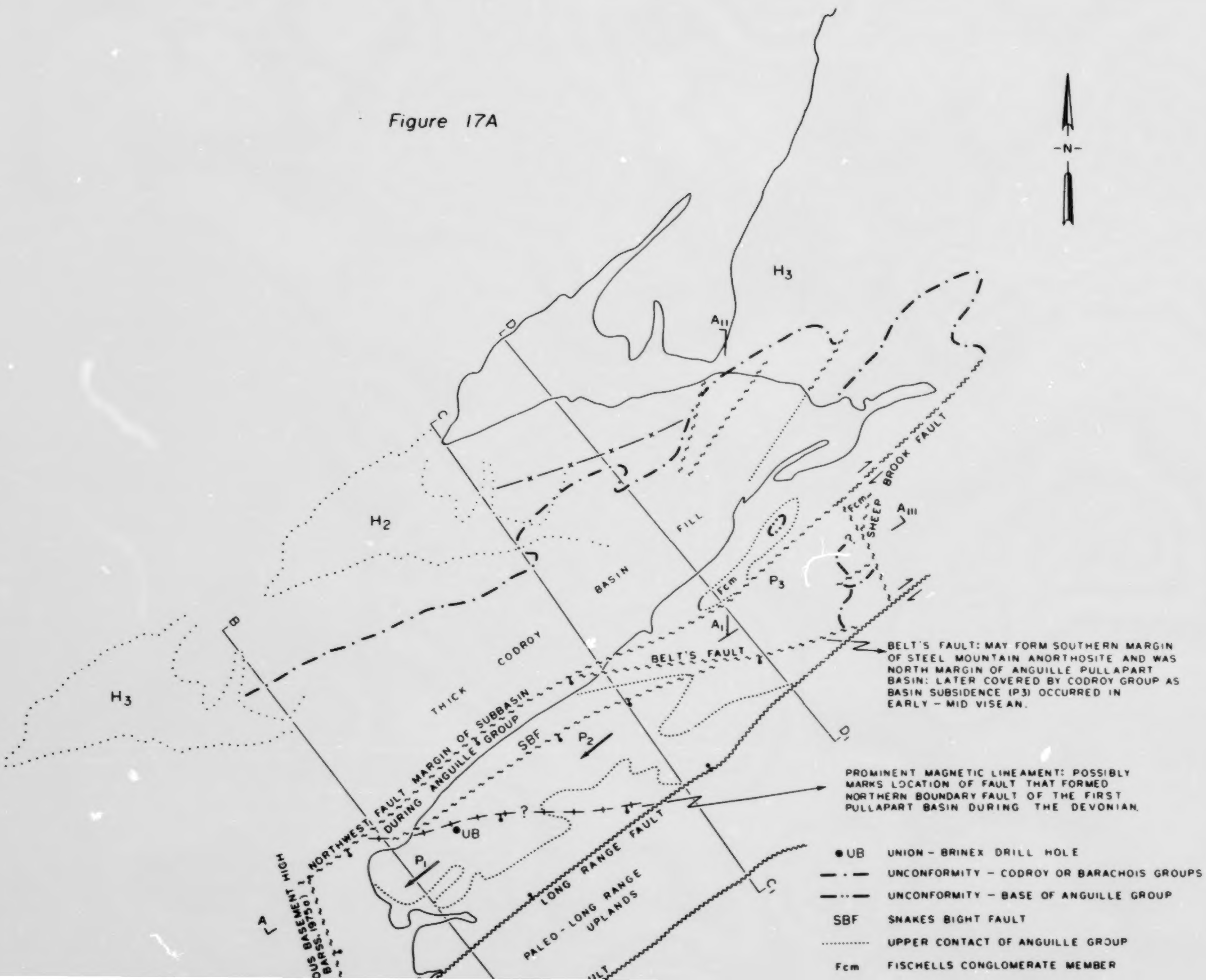

Sequence
FRIARS GULCH
Metres
Sheet Sandstone
Crevassesplay Deposits
Grey
Marsh Flats
Grey
Grey
Black
Grey
Grey
SHALE
SILTSTONE
SANDSTONE
Section 6
Upper Shale Sequence
FRIARS GULCH
Metres
Grey
Channel Sandstone
Turbidite-like Sandstone-Crevassesplay Deposit
Grey
Lacustrine Black
Channel Sandstone
SHALE
Section 7
Fining-upward Sandstone
FRIARS GULCH
Metres
Mostly Red
Red
Mostly Red
Channel Sandstone
Grey
SHALE

Figure 17A

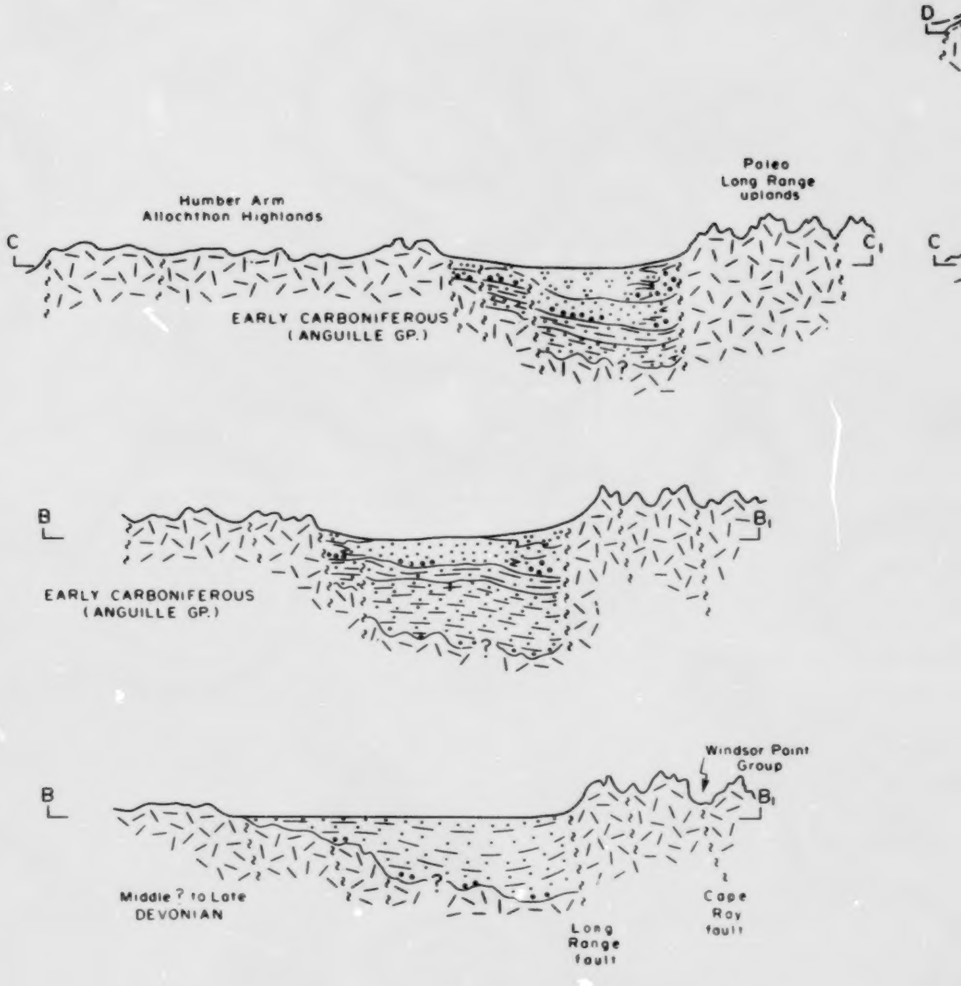

-N-
H3
A11
H2
H3
FILL
BASIN
CODROY
THICK
NORTHWEST FAULT MARGIN OF SUBBASIN DURING ANGUILLE GROUP
BELT'S FAULT
SHEEP BROOK FAULT
Fcm
P3
A1
A111
SBF
P2
P1
UB
LONG RANGE FAULT
PALEO-LONG RANGE UPLANDS
B
C
D
D1
C1
A
OUS BASEMENT HIGH
BARSS, 1975a)

BELT'S FAULT: MAY FORM SOUTHERN MARGIN OF STEEL MOUNTAIN ANORTHOSITE AND WAS NORTH MARGIN OF ANGUILLE PULLAPART BASIN: LATER COVERED BY CODROY GROUP AS BASIN SUBSIDENCE (P3) OCCURRED IN EARLY – MID VISEAN.

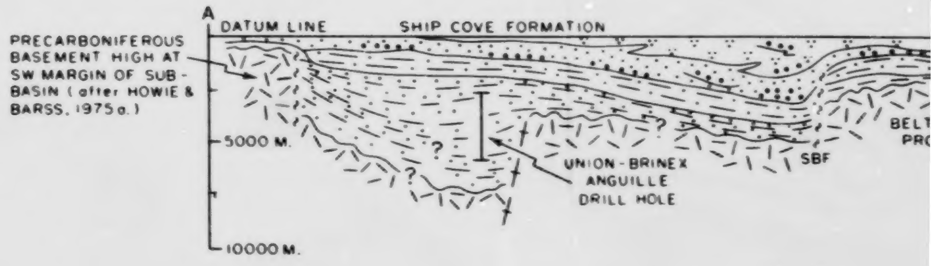
PROMINENT MAGNETIC LINEAMENT: POSSIBLY MARKS LOCATION OF FAULT THAT FORMED NORTHERN BOUNDARY FAULT OF THE FIRST PULLAPART BASIN DURING THE DEVONIAN.

● UB UNION – BRINEX DRILL HOLE
UNCONFORMITY – CODROY OR BARACHOIS GROUPS
UNCONFORMITY – BASE OF ANGUILLE GROUP
SBF SNAKES BIGHT FAULT
UPPER CONTACT OF ANGUILLE GROUP
Fcm FISCHELLS CONGLOMERATE MEMBER

Figure 17B


D
C
C
C1
Humber Arm Allochthon Highlands
Paleo Long Range uplands
EARLY CARBONIFEROUS (ANGUILLE GP.)
B
B1
EARLY CARBONIFEROUS (ANGUILLE GP.)
B
B1
Windsor Point Group
Middle ? to Late DEVONIAN
Long Range fault
Cape Ray fault

Subbasin during Late Devonian and Early Carboniferous (Anguille Group)


A
DATUM LINE
SHIP COVE FORMATION
PRECARBONIFEROUS BASEMENT HIGH AT SW MARGIN OF SUB-BASIN (after HOWIE & BARSS, 1975a.)
5000 M.
10000 M.
UNION-BRINEX ANGUILLE DRILL HOLE
SBF
BELT
PRO

Subbasin during deposition of basal Codroy

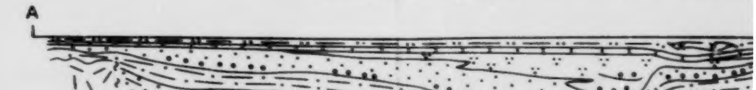


Figure 17B

FOLDOUT B

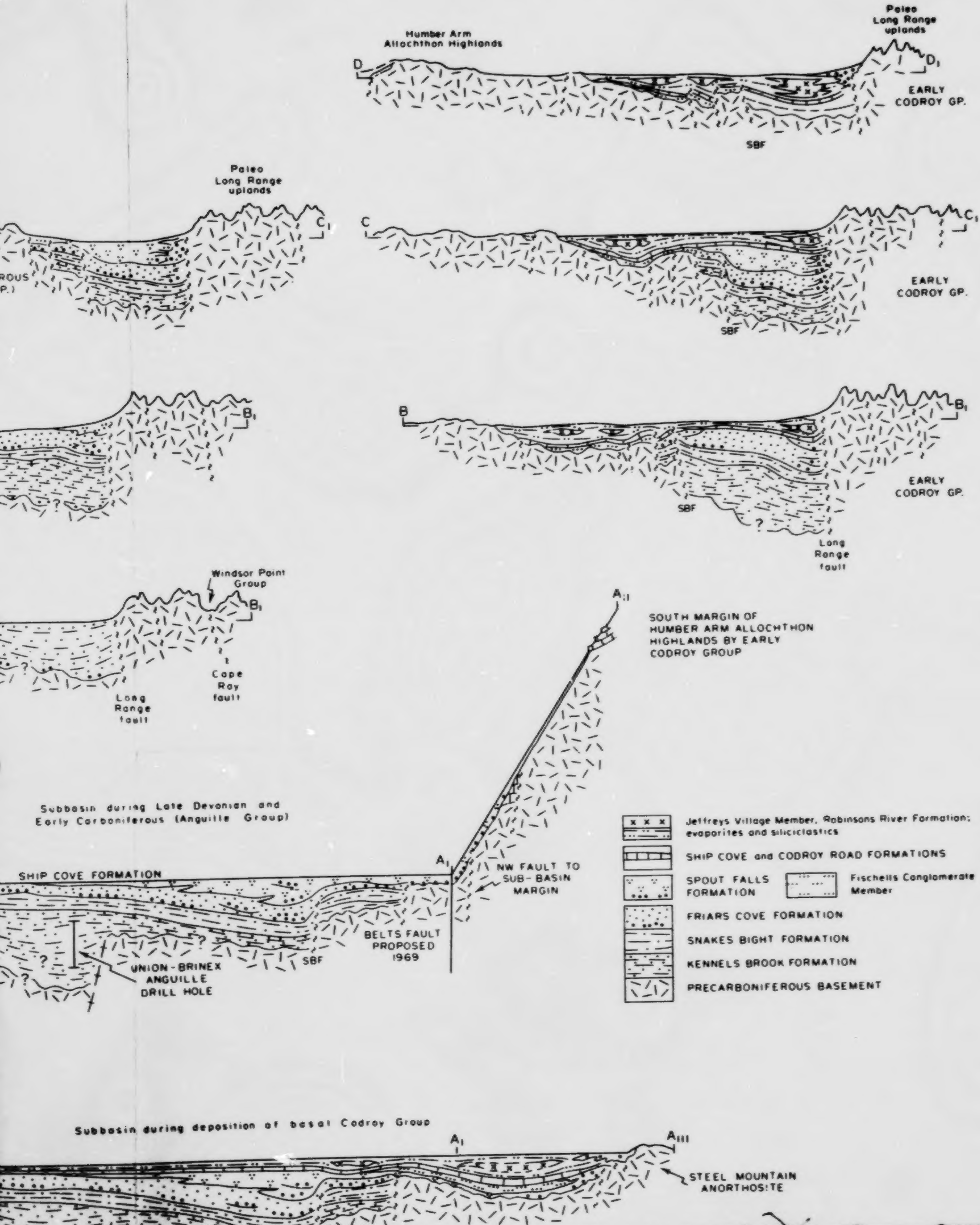

Humber Arm
Allochthon Highlands
D
Paleo
Long Range
uplands
D1
EARLY
CODROY GP.
SBF
Paleo
Long Range
uplands
C1
ROUS
P.)
?
C
C1
EARLY
CODROY GP.
SBF
B1
?
B
B1
EARLY
CODROY GP.
SBF
?
Long
Range
fault
Windsor Point
Group
B1
?
Cape
Ray
fault
Long
Range
fault
A11
SOUTH MARGIN OF
HUMBER ARM ALLOCHTHON
HIGHLANDS BY EARLY
CODROY GROUP
Subbasin during Late Devonian and
Early Carboniferous (Anguille Group)
SHIP COVE FORMATION
A1
NW FAULT TO
SUB-BASIN
MARGIN
BELTS FAULT
PROPOSED
1969
SBF
?
?
?
UNION-BRINEX
ANGUILLE
DRILL HOLE
Jeffreys Village Member, Robinsons River Formation;
evaporites and siliciclastics
SHIP COVE and CODROY ROAD FORMATIONS
SPOUT FALLS
FORMATION
Fischells Conglomerate
Member
FRIARS COVE FORMATION
SNAKES BIGHT FORMATION
KENNELS BROOK FORMATION
PRECARBONIFEROUS BASEMENT
Subbasin during deposition of basal Codroy Group
A1
A111
STEEL MOUNTAIN
ANORTHOSITE

Figure 17A

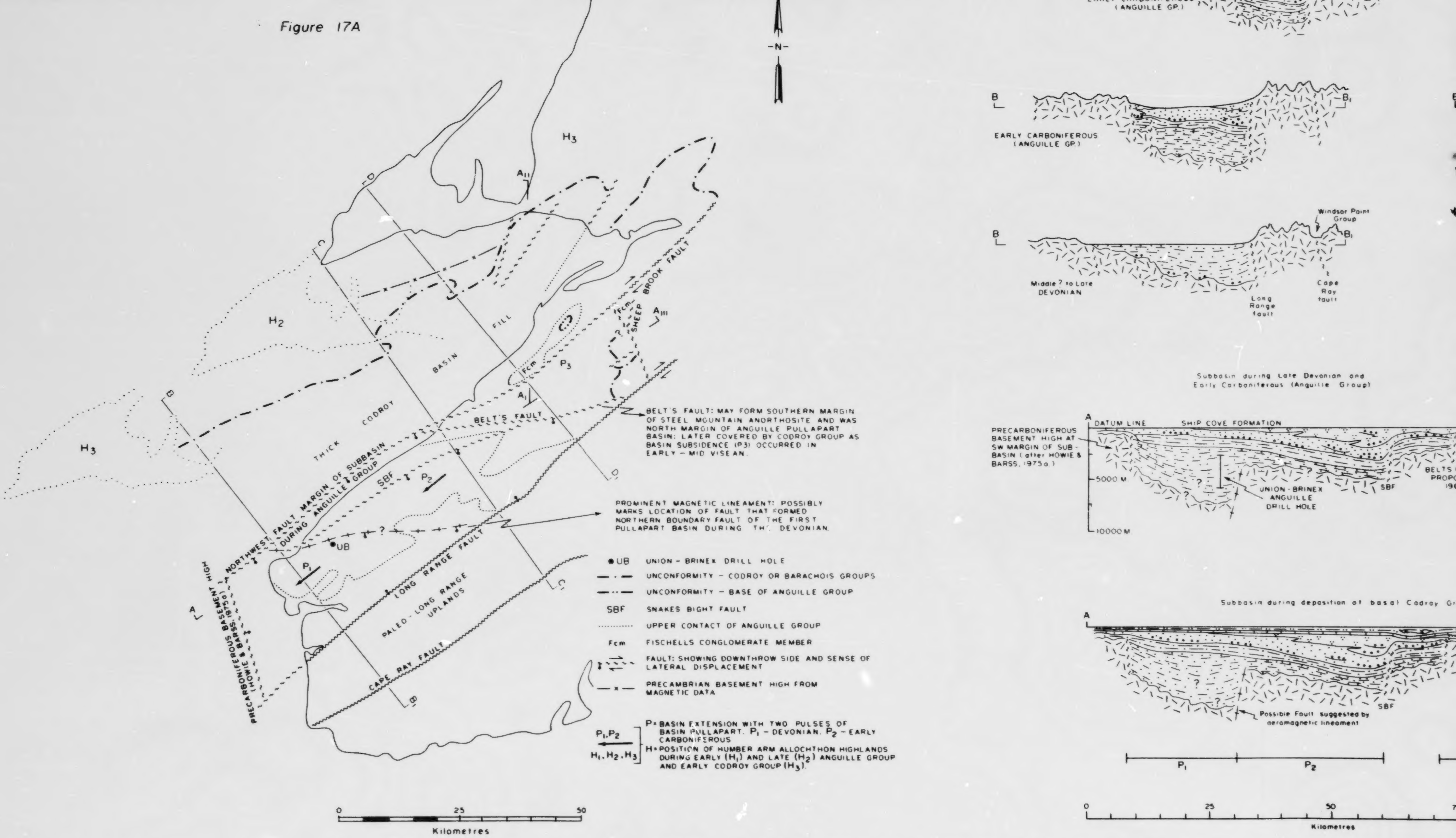
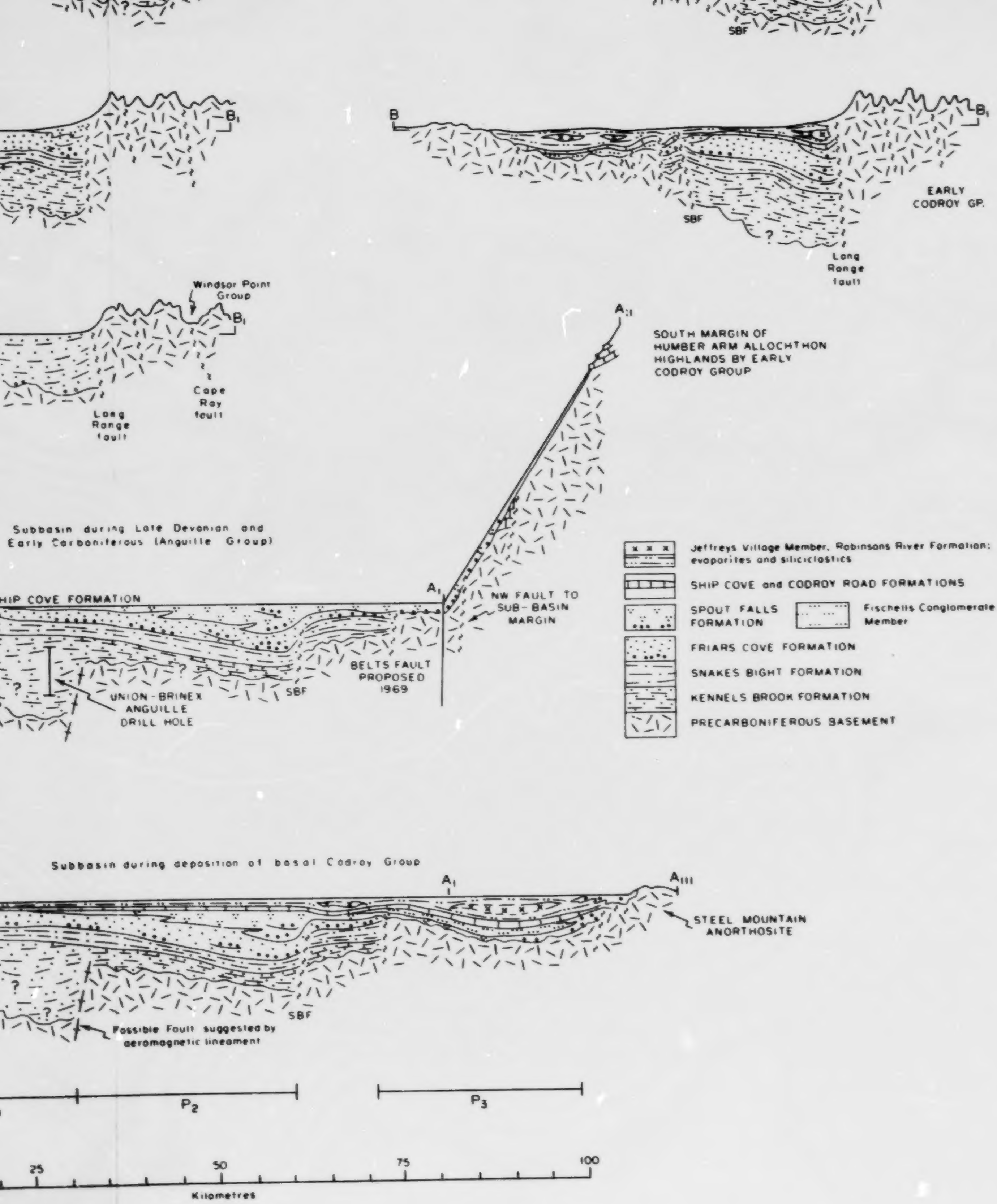
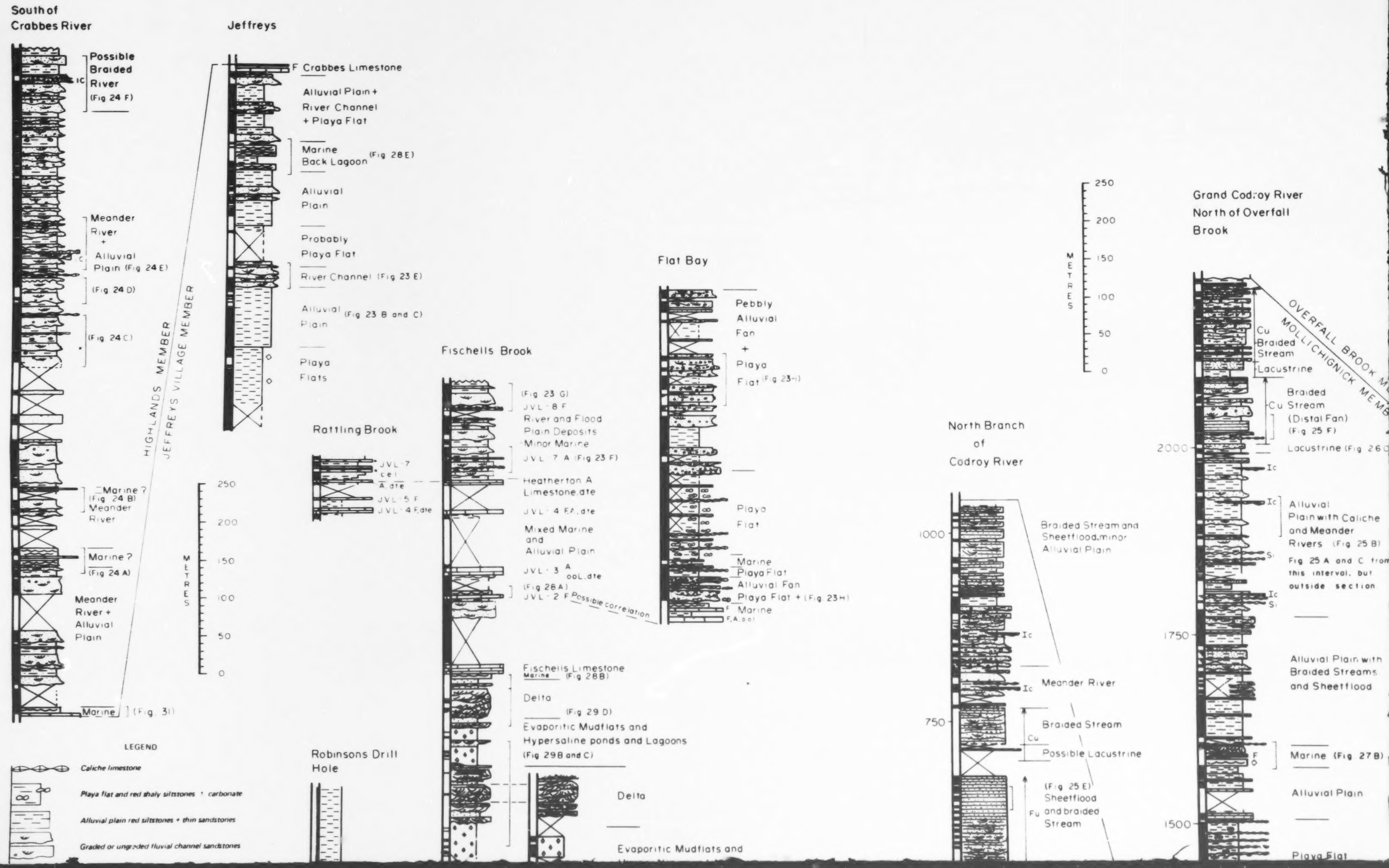

-N-
H3
H2
H3
A11
A111
A1
A
B
B1
C
D
P3
P2
P1
Fcm
SBF
UB
THICK CODROY BASIN FILL
BELT'S FAULT
SHEEP BROOK FAULT
NORTHWEST FAULT MARGIN OF SUBBASIN DURING ANGUILLE GROUP
PRECARBONIFEROUS BASEMENT HIGH (HOWIE & BARSS, 1975a)
LONG RANGE FAULT
PALEO - LONG RANGE UPLANDS
CAPE RAY FAULT
BELT'S FAULT: MAY FORM SOUTHERN MARGIN OF STEEL MOUNTAIN ANORTHOSITE AND WAS NORTH MARGIN OF ANGUILLE PULLAPART BASIN; LATER COVERED BY CODROY GROUP AS BASIN SUBSIDENCE (P3) OCCURRED IN EARLY - MID VISEAN.
PROMINENT MAGNETIC LINEAMENT: POSSIBLY MARKS LOCATION OF FAULT THAT FORMED NORTHERN BOUNDARY FAULT OF THE FIRST PULLAPART BASIN DURING THE DEVONIAN.
●UB UNION - BRINEX DRILL HOLE
UNCONFORMITY - CODROY OR BARACHOIS GROUPS
UNCONFORMITY - BASE OF ANGUILLE GROUP
SBF SNAKES BIGHT FAULT
UPPER CONTACT OF ANGUILLE GROUP
Fcm FISCHELLS CONGLOMERATE MEMBER
FAULT: SHOWING DOWNTHROW SIDE AND SENSE OF LATERAL DISPLACEMENT
PRECAMBRIAN BASEMENT HIGH FROM MAGNETIC DATA
P1, P2 / H1, H2, H3
P = BASIN EXTENSION WITH TWO PULSES OF BASIN PULLAPART. P1 - DEVONIAN. P2 - EARLY CARBONIFEROUS
H = POSITION OF HUMBER ARM ALLOCHTHON HIGHLANDS DURING EARLY (H1) AND LATE (H2) ANGUILLE GROUP AND EARLY CODROY GROUP (H3).
0 25 50
Kilometres
EARLY CARBONIFEROUS (ANGUILLE GP.)
B
B1
EARLY CARBONIFEROUS (ANGUILLE GP.)
Windsor Point Group
Middle ? to Late DEVONIAN
Long Range fault
Cape Ray fault
Subbasin during Late Devonian and Early Carboniferous (Anguille Group)
A
DATUM LINE
SHIP COVE FORMATION
PRECARBONIFEROUS BASEMENT HIGH AT SW MARGIN OF SUB-BASIN (after HOWIE & BARSS, 1975a)
5000 M
10000 M
UNION - BRINEX ANGUILLE DRILL HOLE
SBF
BELTS
PROPO
196
Subbasin during deposition of basal Codroy Gr
SBF
Possible Fault suggested by aeromagnetic lineament
P1
P2
0 25 50
Kilometres

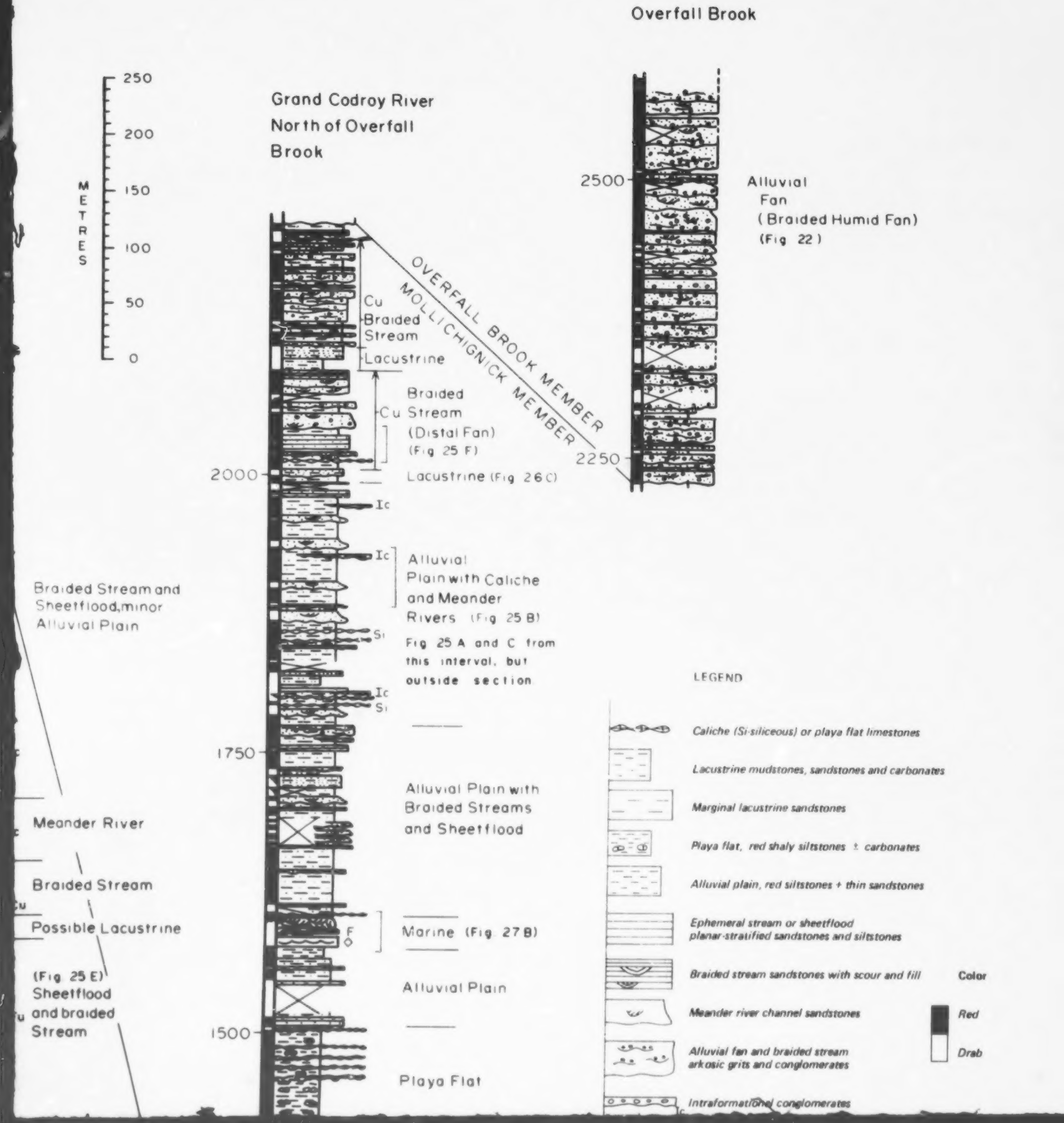
Figure 17: **17A**. Map illustrating main geologic structures and displaced terranes believed to have influenced the Bay St. George subbasin as it evolved as a pull-apart basin during the Late Devonian and Early Carboniferous. **17B**. Cross sections across and along the axis of the subbasin showing distribution of formations in the three basin-fill sequences linked to the basin pull-apart model.


SBF
B
B₁
EARLY CODROY GP.
SBF
Long Range fault
Windsor Point Group
B₁
Cape Ray fault
Long Range fault
A₁₁
SOUTH MARGIN OF HUMBER ARM ALLOCHTHON HIGHLANDS BY EARLY CODROY GROUP
Subbasin during Late Devonian and Early Carboniferous (Anguille Group)
HIP COVE FORMATION
A₁
NW FAULT TO SUB-BASIN MARGIN
BELTS FAULT PROPOSED 1969
SBF
UNION-BRINEX ANGUILLE DRILL HOLE
Jeffreys Village Member, Robinsons River Formation; evaporites and siliciclastics
SHIP COVE and CODROY ROAD FORMATIONS
SPOUT FALLS FORMATION
Fischells Conglomerate Member
FRIARS COVE FORMATION
SNAKES BIGHT FORMATION
KENNELS BROOK FORMATION
PRECARBONIFEROUS BASEMENT
Subbasin during deposition of basal Codroy Group
A₁
A₁₁₁
STEEL MOUNTAIN ANORTHOSITE
SBF
Possible Fault suggested by aeromagnetic lineament
P₂
P₃
25
50
75
100
Kilometres

to have
the Late
kis of the
ed to the


South of Crabbes River
Possible Braided River (Fig 24 F)
Ic
Meander River + Alluvial Plain (Fig 24 E)
(Fig 24 D)
(Fig 24 C)
Marine ? (Fig 24 B) Meander River
Marine ? (Fig 24 A)
Meander River + Alluvial Plain
Marine (Fig. 31)
HIGHLANDS MEMBER
JEFFREYS VILLAGE MEMBER
Jeffreys
F Crabbes Limestone
Alluvial Plain + River Channel + Playa Flat
Marine Back Lagoon (Fig 28 E)
Alluvial Plain
Probably Playa Flat
River Channel (Fig 23 E)
Alluvial Plain (Fig 23 B and C)
Playa Flats
METRES
250
200
150
100
50
0
Rattling Brook
JVL-7 cel
A dte
JVL-5 F
JVL-4 F dte
Fischells Brook
(Fig 23 G)
JVL-8 F
River and Flood Plain Deposits Minor Marine
JVL-7 A (Fig 23 F)
Heatherton A Limestone dte
JVL-4 FA dte
Mixed Marine and Alluvial Plain
JVL-3 A ooL dte
(Fig 28 A)
JVL-2 F
Possible correlation
Fischells Limestone
Marine (Fig 28 B)
Delta
(Fig 29 D)
Evaporitic Mudflats and Hypersaline ponds and Lagoons (Fig 29 B and C)
Robinsons Drill Hole
Delta
Evaporitic Mudflats and
Flat Bay
Pebbly Alluvial Fan + Playa Flat (Fig 23-I)
Playa Flat
Marine
Playa Flat
Alluvial Fan
Playa Flat + (Fig 23 H)
F Marine
F,A,ool
METRES
250
200
150
100
50
0
North Branch of Codroy River
1000
750
Braided Stream and Sheetflood, minor Alluvial Plain
Ic
Meander River
Ic
Braided Stream
Cu
Possible Lacustrine
(Fig 25 E) Sheetflood and braided Stream
Fu
Grand Codroy River North of Overfall Brook
OVERFALL BROOK M
MOLLICHIGNICK MEMB
Cu Braided Stream
Lacustrine
Braided Stream (Distal Fan) (Fig 25 F)
Cu
2000
Lacustrine (Fig 26 C
Ic
Ic
Alluvial Plain with Caliche and Meander Rivers (Fig 25 B)
Si
Fig 25 A and C from this interval, but outside section
Ic
Si
1750
Alluvial Plain with Braided Streams and Sheetflood
F
Marine (Fig 27 B)
Alluvial Plain
1500
Playa Flat
LEGEND
Caliche limestone
Playa flat and red shaly siltstones + carbonate
Alluvial plain red siltstones + thin sandstones
Graded or ungraded fluvial channel sandstones

FOLDOUT C


Overfall Brook
250
200
150
100
50
0
METRES
Grand Codroy River
North of Overfall
Brook
2500
Alluvial
Fan
(Braided Humid Fan)
(Fig. 22)
OVERFALL BROOK MEMBER
MOLLICHIGNICK MEMBER
Cu
Braided
Stream
Lacustrine
Braided
Cu Stream
(Distal Fan)
(Fig. 25 F)
2250
2000
Lacustrine (Fig. 26 C)
Ic
Ic
Alluvial
Plain with Caliche
and Meander
Rivers (Fig. 25 B)
Si
Fig. 25 A and C from
this interval, but
outside section
Ic
Si
Braided Stream and
Sheetflood, minor
Alluvial Plain
1750
Alluvial Plain with
Braided Streams
and Sheetflood
Meander River
Braided Stream
Cu
Possible Lacustrine
F
Marine (Fig. 27 B)
(Fig. 25 E)
Sheetflood
and braided
Stream
Alluvial Plain
1500
Playa Flat
LEGEND
Caliche (Si-siliceous) or playa flat limestones
Lacustrine mudstones, sandstones and carbonates
Marginal lacustrine sandstones
Playa flat, red shaly siltstones ± carbonates
Alluvial plain, red siltstones + thin sandstones
Ephemeral stream or sheetflood
planar-stratified sandstones and siltstones
Braided stream sandstones with scour and fill
Meander river channel sandstones
Alluvial fan and braided stream
arkosic grits and conglomerates
Intraformational conglomerates
Color
Red
Drab

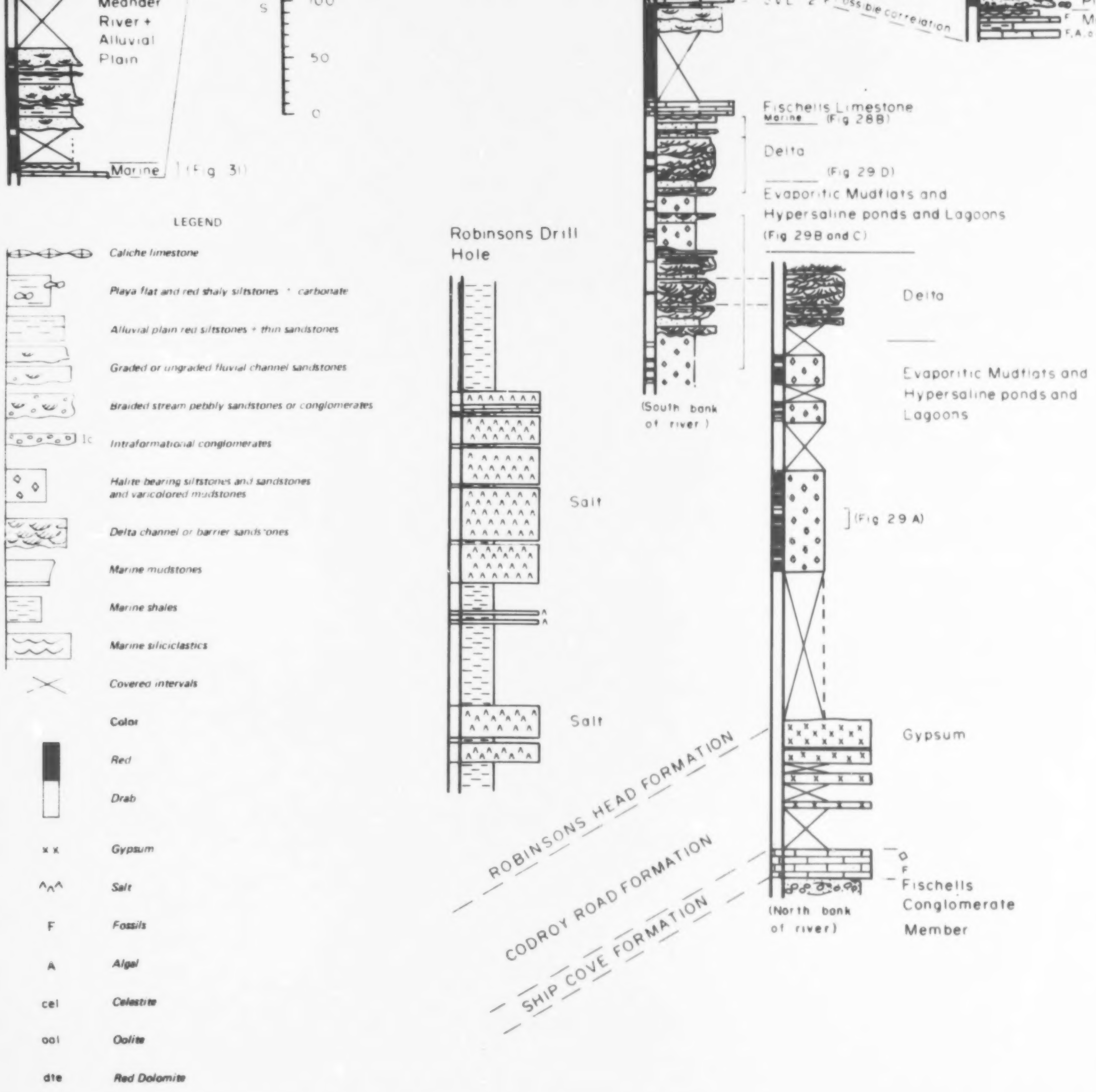

Meander
River +
Alluvial
Plain
Marine
(Fig. 31)
100
50
0
Possible correlation
Playa Flat + (Fig 23A)
Marine
F,A,ool
Fischells Limestone
Marine (Fig 28B)
Delta
(Fig 29 D)
Evaporitic Mudflats and
Hypersaline ponds and Lagoons
(Fig 29B and C)
Robinsons Drill
Hole
Salt
Salt
(South bank
of river)
Delta
Evaporitic Mudflats and
Hypersaline ponds and
Lagoons
(Fig 29 A)
Gypsum
Fischells
Conglomerate
Member
(North bank
of river)
ROBINSONS HEAD FORMATION
CODROY ROAD FORMATION
SHIP COVE FORMATION
LEGEND
Caliche limestone
Playa flat and red shaly siltstones + carbonate
Alluvial plain red siltstones + thin sandstones
Graded or ungraded fluvial channel sandstones
Braided stream pebbly sandstones or conglomerates
Ic
Intraformational conglomerates
Halite bearing siltstones and sandstones
and varicolored mudstones
Delta channel or barrier sandstones
Marine mudstones
Marine shales
Marine siliciclastics
Covered intervals
Color
Red
Drab
x x
Gypsum
^^^
Salt
F
Fossils
A
Algal
cel
Celestite
ool
Oolite
dte
Red Dolomite

Figure 20: Sections compiled for the Jeffrey's Village and Highlands Members of the Robinsons River Formation, St. George's Bay lowlands. Flat Bay section is not correlated specifically with the Fischells Brook section but possibly lies at the interval equivalent to the section including and overlying limestone JVL-2. Codroy Road and Ship Cove Formations are shown at base of Fischells Brook section.

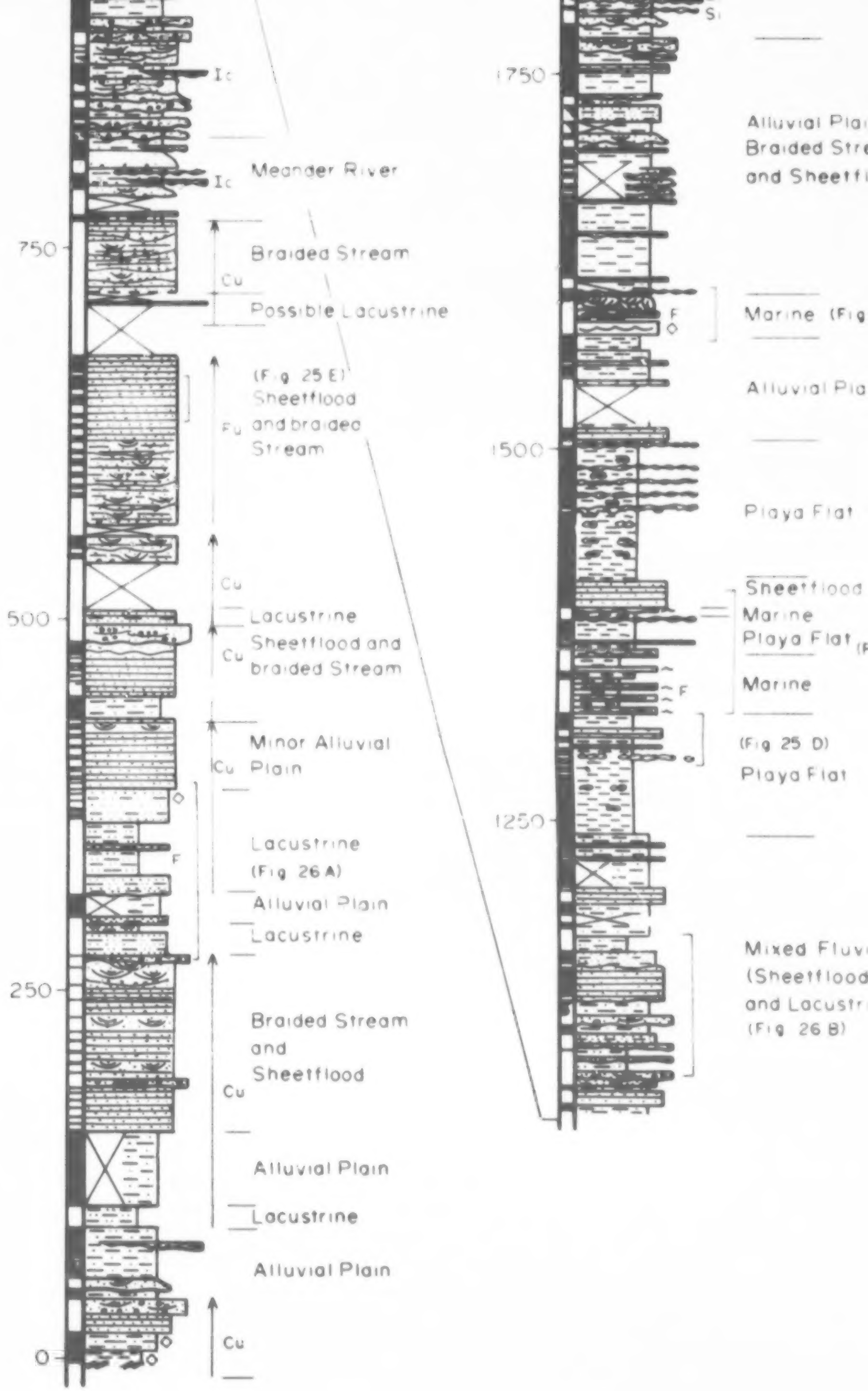
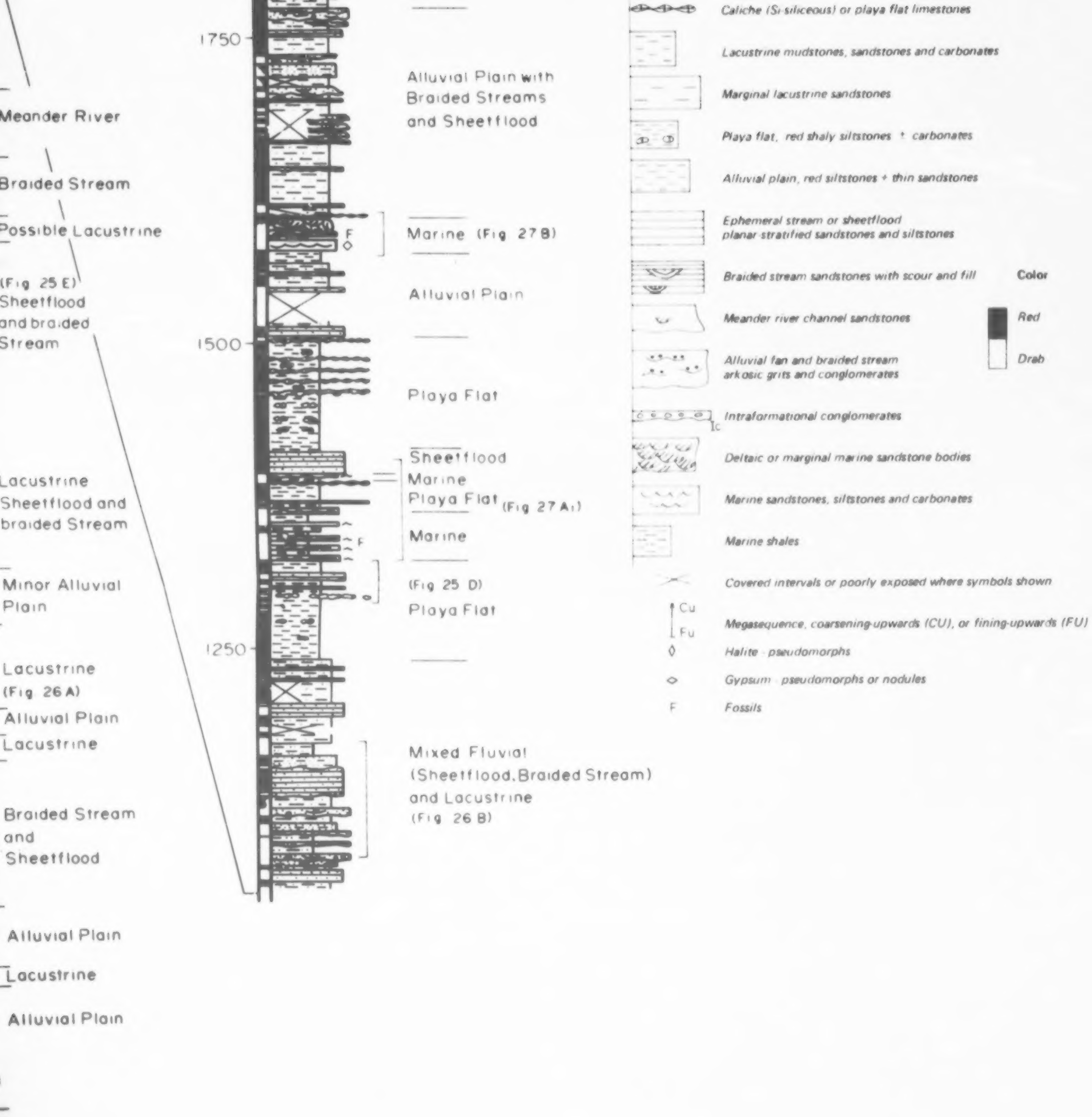

Ic
Ic
Meander River
750
Braided Stream
Cu
Possible Lacustrine
(Fig 25 E)
Sheetflood
and braided
Stream
Fu
Cu
500
Lacustrine
Sheetflood and
braided Stream
Cu
Minor Alluvial
Plain
Cu
Lacustrine
(Fig 26 A)
F
Alluvial Plain
Lacustrine
250
Braided Stream
and
Sheetflood
Cu
Alluvial Plain
Lacustrine
Alluvial Plain
Cu
0
1750
Alluvial Pla
Braided Str
and Sheetf
F
Marine (Fig
Alluvial Pla
1500
Playa Flat
Sheetflood
Marine
Playa Flat
Marine
F
(Fig 25 D)
Playa Flat
1250
Mixed Fluv
(Sheetflood
and Lacustr
(Fig 26 B)

Figure 21: Type sections of the Mollichignick and Overfa Formation, Codroy lowlands.



1750
1500
1250
Meander River
Braided Stream
Possible Lacustrine
(Fig 25 E)
Sheetflood and braided Stream
Lacustrine
Sheetflood and braided Stream
Minor Alluvial Plain
Lacustrine
(Fig 26 A)
Alluvial Plain
Lacustrine
Braided Stream and Sheetflood
Alluvial Plain
Lacustrine
Alluvial Plain
Alluvial Plain with Braided Streams and Sheetflood
Marine (Fig 27 B)
F
Alluvial Plain
Playa Flat
Sheetflood
Marine
Playa Flat (Fig 27 A1)
Marine
F
(Fig 25 D)
Playa Flat
Mixed Fluvial (Sheetflood, Braided Stream) and Lacustrine
(Fig 26 B)
Caliche (Si siliceous) or playa flat limestones
Lacustrine mudstones, sandstones and carbonates
Marginal lacustrine sandstones
Playa flat, red shaly siltstones ± carbonates
Alluvial plain, red siltstones + thin sandstones
Ephemeral stream or sheetflood planar-stratified sandstones and siltstones
Braided stream sandstones with scour and fill
Meander river channel sandstones
Alluvial fan and braided stream arkosic grits and conglomerates
Intraformational conglomerates
Ic
Deltaic or marginal marine sandstone bodies
Marine sandstones, siltstones and carbonates
Marine shales
Covered intervals or poorly exposed where symbols shown
Cu
Fu
Megasequence, coarsening-upwards (CU), or fining-upwards (FU)
Halite - pseudomorphs
Gypsum - pseudomorphs or nodules
F
Fossils
Color
Red
Drab

Figure 21: Type sections of the Mollichignick and Overfall Brook Members of the Robinsons River Formation, Codroy lowlands.

FIGURE 29

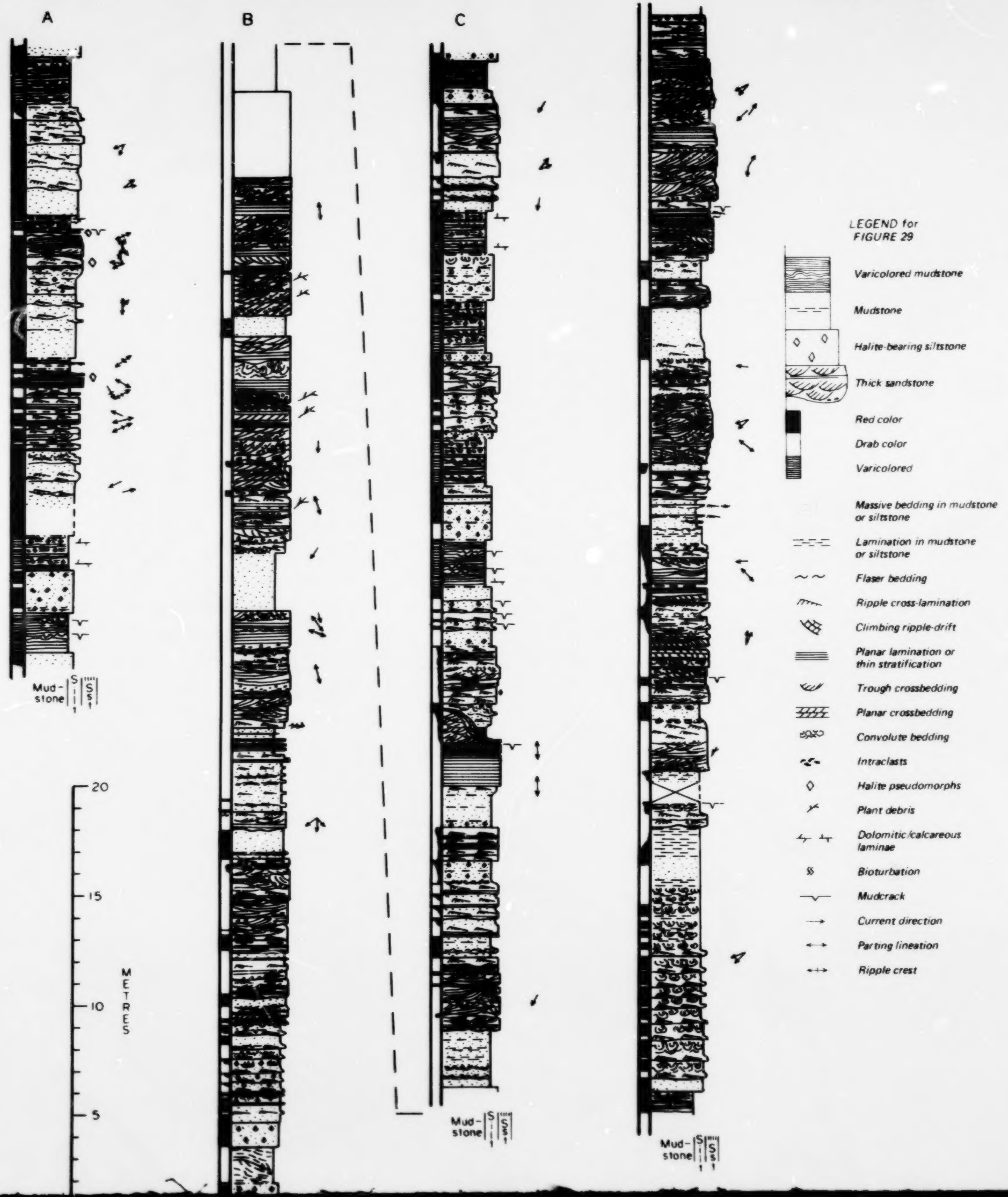
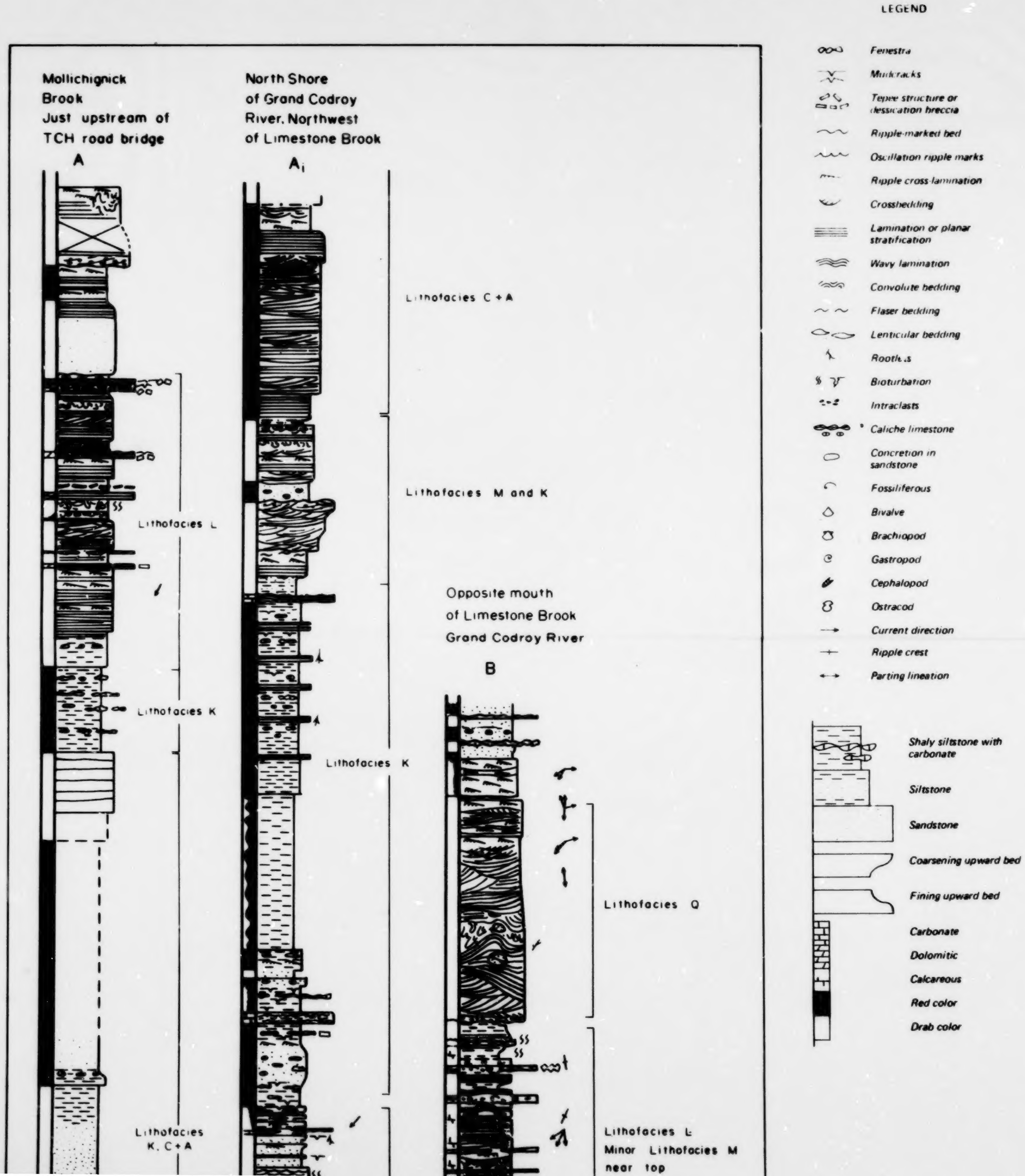

A
B
C
Mud-stone
S
S
20
15
10
5
METRES
LEGEND for FIGURE 29
Varicolored mudstone
Mudstone
Halite-bearing siltstone
Thick sandstone
Red color
Drab color
Varicolored
Massive bedding in mudstone or siltstone
Lamination in mudstone or siltstone
Flaser bedding
Ripple cross-lamination
Climbing ripple-drift
Planar lamination or thin stratification
Trough crossbedding
Planar crossbedding
Convolute bedding
Intraclasts
Halite pseudomorphs
Plant debris
Dolomitic/calcareous laminae
Bioturbation
Mudcrack
Current direction
Parting lineation
Ripple crest

FIGURE 27


LEGEND
Fenestra
Mudcracks
Tepee structure or dessication breccia
Ripple-marked bed
Oscillation ripple marks
Ripple cross-lamination
Crossbedding
Lamination or planar stratification
Wavy lamination
Convolute bedding
Flaser bedding
Lenticular bedding
Rootlets
Bioturbation
Intraclasts
Caliche limestone
Concretion in sandstone
Fossiliferous
Bivalve
Brachiopod
Gastropod
Cephalopod
Ostracod
Current direction
Ripple crest
Parting lineation
Shaly siltstone with carbonate
Siltstone
Sandstone
Coarsening upward bed
Fining upward bed
Carbonate
Dolomitic
Calcareous
Red color
Drab color
Mollichignick Brook Just upstream of TCH road bridge
A
North Shore of Grand Codroy River, Northwest of Limestone Brook
A₁
Opposite mouth of Limestone Brook Grand Codroy River
B
Lithofacies C + A
Lithofacies M and K
Lithofacies L
Lithofacies K
Lithofacies K
Lithofacies Q
Lithofacies K, C+A
Lithofacies L
Minor Lithofacies M near top

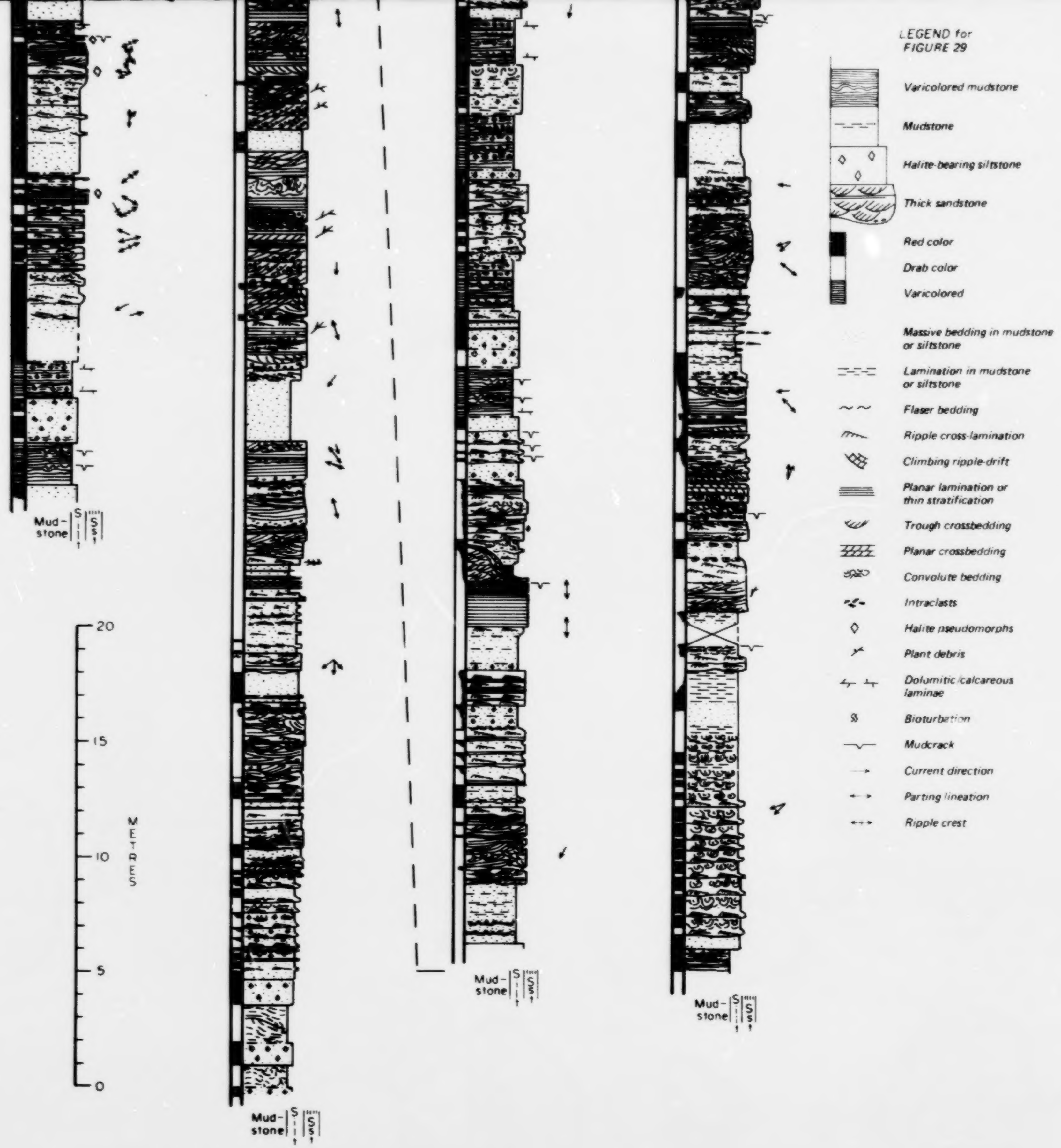
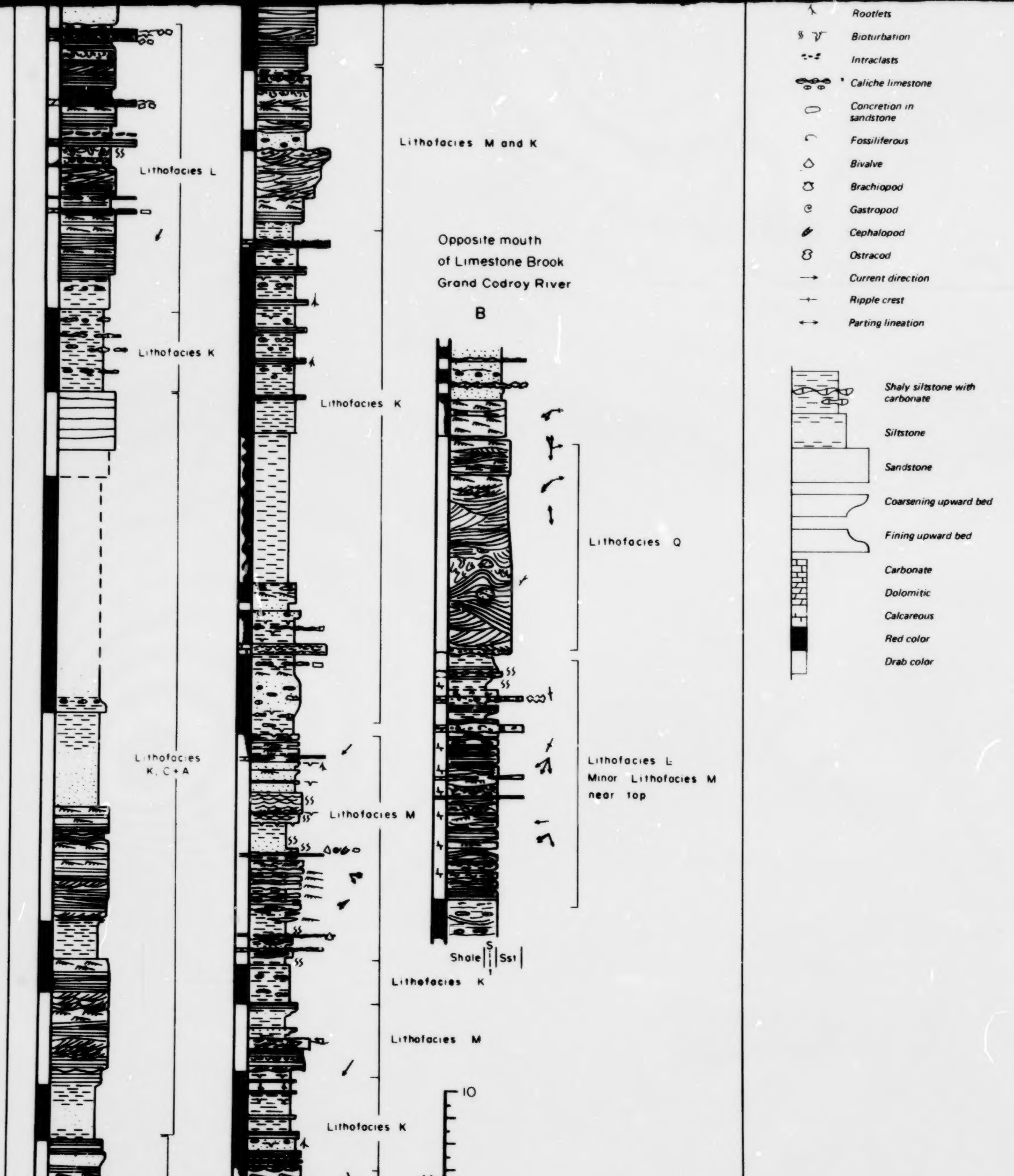

LEGEND for FIGURE 29
Varicolored mudstone
Mudstone
Halite-bearing siltstone
Thick sandstone
Red color
Drab color
Varicolored
Massive bedding in mudstone or siltstone
Lamination in mudstone or siltstone
Flaser bedding
Ripple cross-lamination
Climbing ripple-drift
Planar lamination or thin stratification
Trough crossbedding
Planar crossbedding
Convolute bedding
Intraclasts
Halite pseudomorphs
Plant debris
Dolomitic/calcareous laminae
Bioturbation
Mudcrack
Current direction
Parting lineation
Ripple crest
Mud-stone
S
S
20
15
10
5
0
METRES

Figure 29: Detailed sedimentary sections in the lower part of the Jeffrey's Village Member, Fischells Brook. Sections are arranged in ascending order. Sections A and C consist mostly of mud rocks of lithofacies N and O but also include sandstones of lithofacies Q and strata similar to fine beds of lithofacies B. Sections B and D show transition from lithofacies N and O up into sandstone-dominated sections of lithofacies P and Q.


Lithofacies L
Lithofacies K
Lithofacies K, C+A
Lithofacies M and K
Lithofacies K
Lithofacies M
Lithofacies K
Lithofacies M
Lithofacies K
10
Opposite mouth
of Limestone Brook
Grand Codroy River
B
Lithofacies Q
Lithofacies L
Minor Lithofacies M
near top
Shale S Sst
Rootlets
Bioturbation
Intraclasts
Caliche limestone
Concretion in sandstone
Fossiliferous
Bivalve
Brachiopod
Gastropod
Cephalopod
Ostracod
Current direction
Ripple crest
Parting lineation
Shaly siltstone with carbonate
Siltstone
Sandstone
Coarsening upward bed
Fining upward bed
Carbonate
Dolomitic
Calcareous
Red color
Drab color

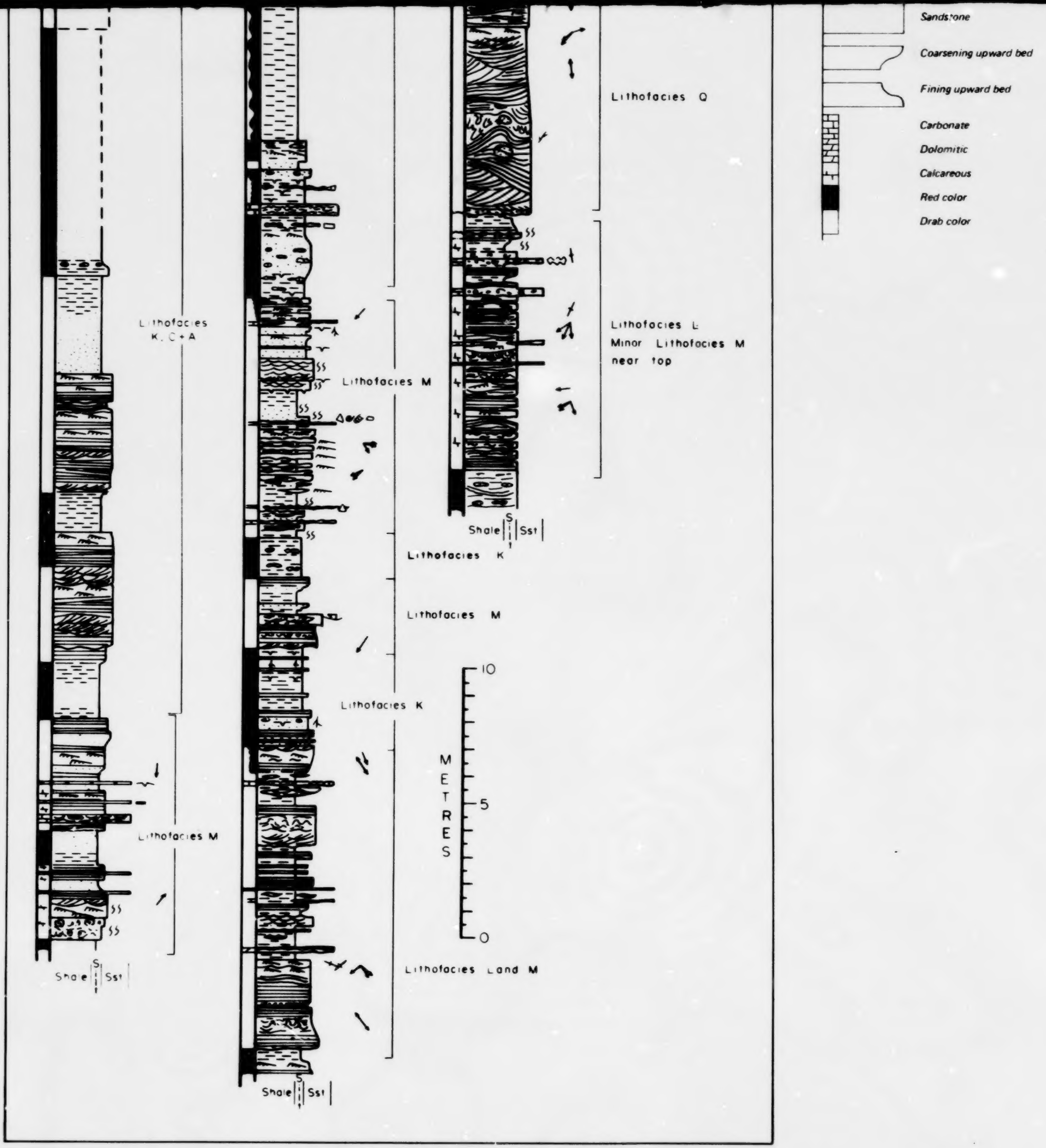

Sandstone
Coarsening upward bed
Fining upward bed
Carbonate
Dolomitic
Calcareous
Red color
Drab color
Lithofacies Q
Lithofacies L
Minor Lithofacies M
near top
Lithofacies
K, C+A
Lithofacies M
Lithofacies K
Lithofacies M
Lithofacies K
Lithofacies M
Lithofacies L and M
METRES
10
5
0
Shale S Sst
Shale S Sst
Shale S Sst

Figure 27: Detailed sedimentological sections in lithofacies K, L, M and Q, Mollichignick Member. Sections A and Ai are of same stratigraphic interval although not correlated precisely. Section B lies approximately 170 m stratigraphically above section Ai. Location of sections A and B is shown in type section of the member, Figure 21.

FIGURE 26

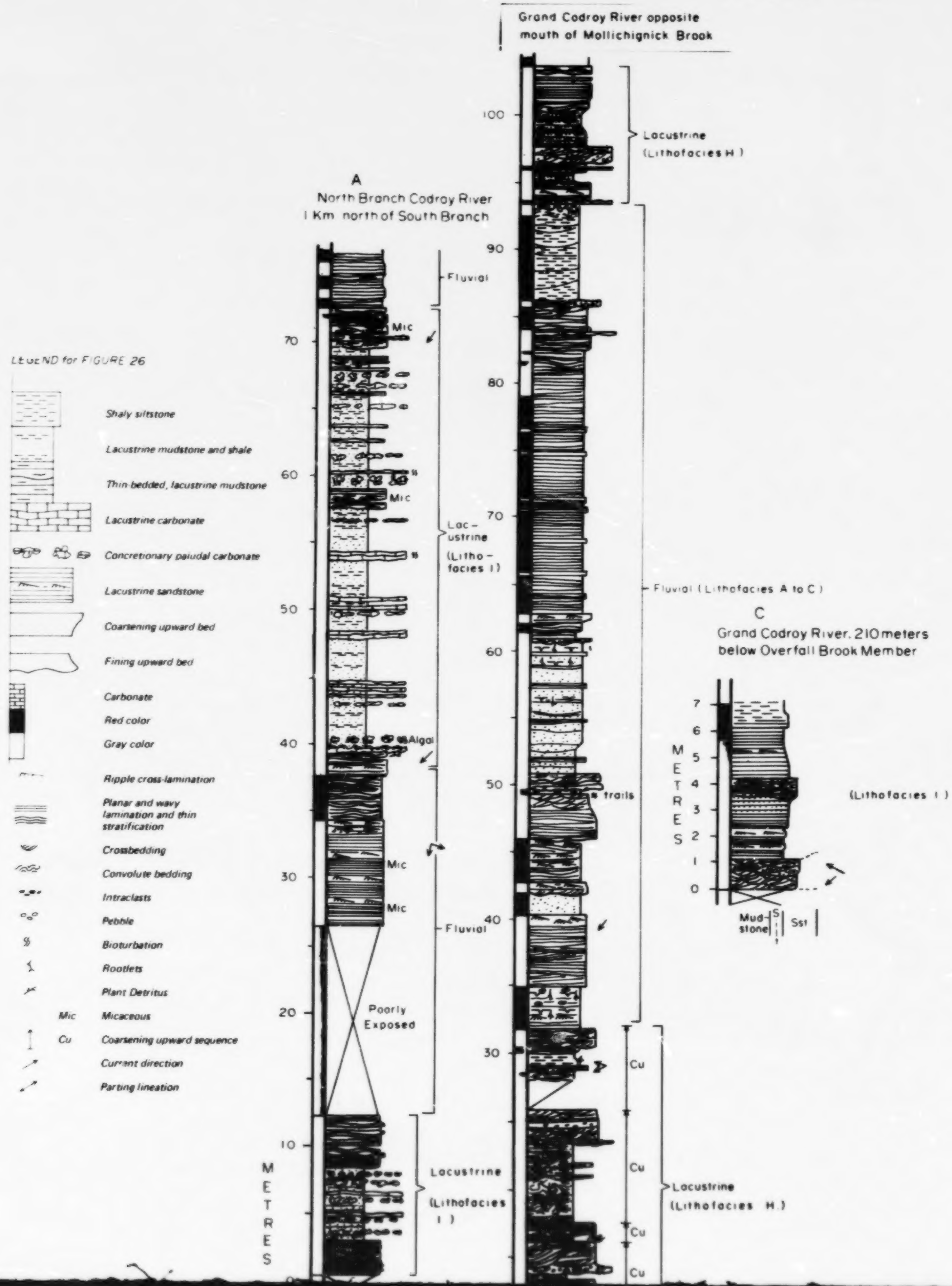
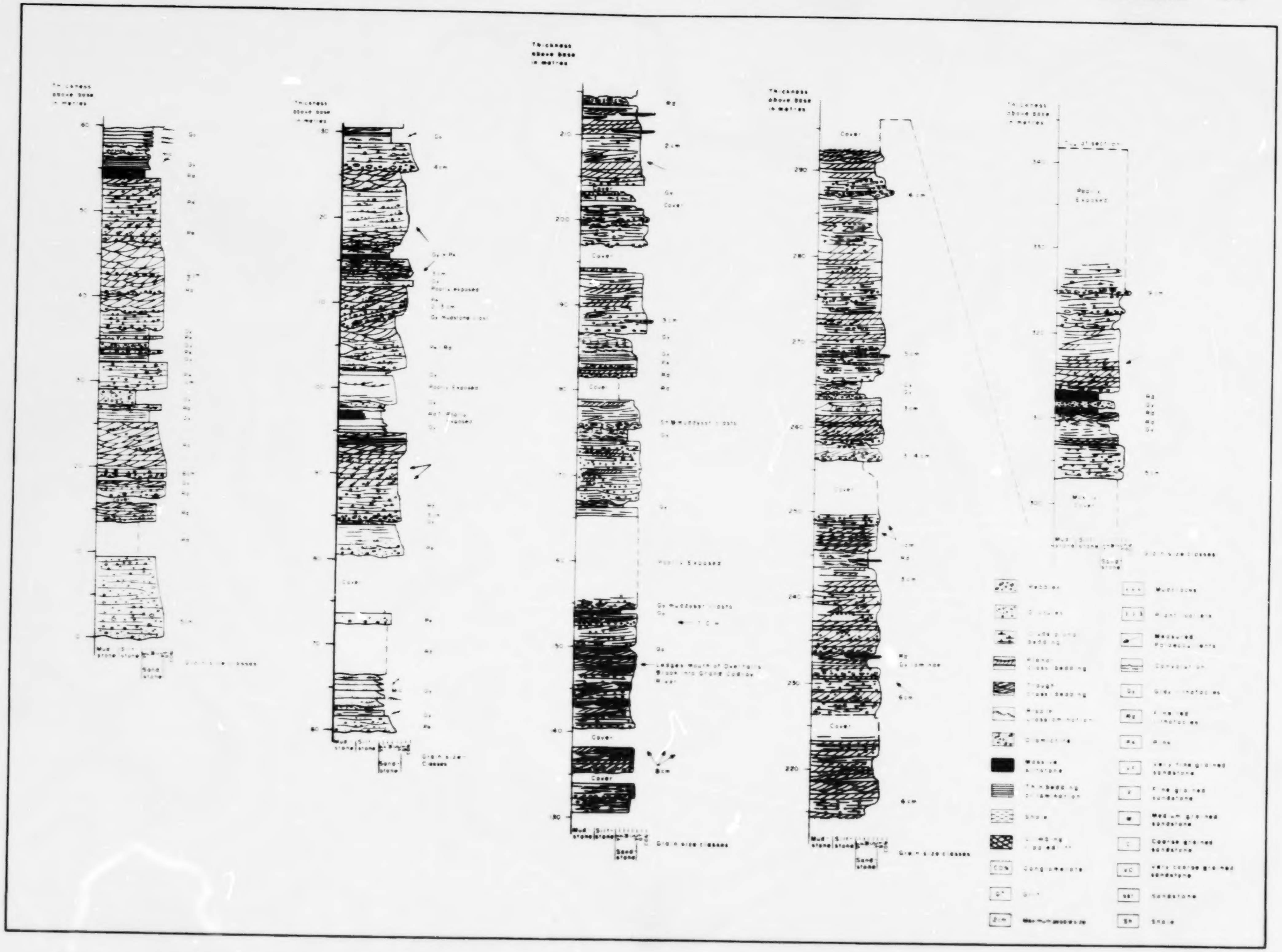

LEGEND for FIGURE 26
Shaly siltstone
Lacustrine mudstone and shale
Thin-bedded, lacustrine mudstone
Lacustrine carbonate
Concretionary paludal carbonate
Lacustrine sandstone
Coarsening upward bed
Fining upward bed
Carbonate
Red color
Gray color
Ripple cross-lamination
Planar and wavy lamination and thin stratification
Crossbedding
Convolute bedding
Intraclasts
Pebble
Bioturbation
Rootlets
Plant Detritus
Mic Micaceous
Cu Coarsening upward sequence
Current direction
Parting lineation
A
North Branch Codroy River
1 Km north of South Branch
METRES
10
20
30
40
50
60
70
Fluvial
Mic
Mic
Lac-ustrine (Litho-facies I)
Algal
Mic
Mic
Fluvial
Poorly Exposed
Lacustrine (Lithofacies I)
B
Grand Codroy River opposite mouth of Mollichignick Brook
100
90
80
70
60
50
40
30
Lacustrine (Lithofacies H)
Fluvial (Lithofacies A to C)
trails
Cu
Cu
Cu
Cu
Lacustrine (Lithofacies H)
C
Grand Codroy River. 210 meters below Overfall Brook Member
METRES
0
1
2
3
4
5
6
7
(Lithofacies I)
Mud-stone
S
Sst

FIGURE 22



Thickness above base in metres
Cover
Poorly exposed
Grain size classes
Mud stone
Silt stone
Sand stone
Ledges mouth of Overfall Brook into Grand Codroy River
Pebbles
Granules
Crude planar bedding
Planar cross bedding
Trough cross bedding
Ripple cross lamination
Diamictite
Massive siltstone
Thin bedding or lamination
Shale
Climbing ripple drift
CGL Conglomerate
St Silt
2cm Maximum pebble size
Mudclasts
Plant debris
Measured Paleocurrents
Convolution
Gx Grey lithofacies
Rd Fine red lithofacies
Pk Pink
vF Very fine grained sandstone
F Fine grained sandstone
M Medium grained sandstone
C Coarse grained sandstone
vC Very coarse grained sandstone
SST Sandstone
Sh Shale

Figure 22: Type section of Overfall Brook Member, Overfall Brook.

TABLE 2

NEW BRUNSWICK (compiled from GUSSOW, 1953; GREINER, 1962; EVANS, 1970)	**NOVA SCOTIA** from Bell (1960)	**CAPE BRETON** (from Kelley, 1967; Kelley and Mackasey, 1963; Neale and Kelley, 1960; Cote, 1964) **SOUTHWEST**	**NORTH**	**NEWFOUNDLAND** (Knight, this report; Baird, 1951) **BAY ST. GEORGE SUB-BASIN**
MONCTON GROUP		**HORTON GROUP**		**ANGUILLE GROUP**
HILLSBOROUGH FORMATION (up to 870 m thick) *Red and green gray sandstone, pink arkosic conglomerate, shale, basal volcanic ash bed.* Possible Windsor equivalent, i.e. Upper Mississippian WELDON FORMATION (up to 1500 m) *Red siltstone, shale, red to green conglomerate, limestone concretions* SHARP TO GRADATIONAL	CHEVERIE FORMATION (about 200 m thick) *Red siltstone plus green-gray and gray siltstone and shale; red, purple, green-gray arkosic conglomerate and minor sandstone; limestone concretions*	STRATHLORNE – AINSLIE FORMATION AINSLIE MEMBER (560 m thick) *Red and gray sandstone and siltstone; some red conglomerate becoming dominant to southeast* *More gray sandstone and shale, some limestone breccias near base* CONFORMABLE	AINSLIE FORMATION (about 480 m thick) *Red, purple, buff sandstone and conglomerate, red and gray siltstone and shale; minor limestone* *Gray shales, siltstones, and sandstones with limestone interbeds becoming common in northernmost outcrops (Neale and Kelley, 1960, Cote, 1964)*	SPOUT FALLS FORMATION SW *Green-gray and red sandstone, red siltstone. Thins rapidly south, pink arkose in north. Conglomerates important northeastwards* FISCHELLS CONGLOMERATE MEMBER NE
S ALBERT FORMATION up to 1200 m thick Hiram Brook Member *Gray siltstone, sandstone, bituminous, gray shale and lenticular sandstone passing north to silty dolomite, gray calcareous and bituminous shale* Frederick Brook Member *Thin laminated, gray bituminous shales (oil shales), minor siltstone, deformed units. Becomes siltier to east and includes more argillaceous limestone to west and north* Dawson Settlement Member *Siltstone and feldspathic sandstone (lenticular) in south passing north into more limestones* *Gray conglomerate and sandstone with algal and oolitic limestone in south, passing north into shale limestone and siltstone* N GAUTREAU FORMATION up to 480 m thick *Salt, gypsum anhydrite dolomite, limestone, shale* GRADATIONAL AND LOCAL DISCONFORMITY	HORTON BLUFF FORMATION (840 1230 m thick) Upper Arenaceous Member (about 120 m thick) *Gray sandstone, minor conglomerate, gray and black gray shales, limestone, ferruginous dolomites, trace fossils* Middle Argillaceous Member *Upper sequence of black shales thin gray sandstones and ferruginous limestones; fossil fish, ostracods, trace fossils (345 m thick). Lower sequence of gray sandstones and black shales, plant fossils and trace fossils (210 to 630 m thick)* Basal feldspathic conglomerate and sandstone member (180 m thick) *Gray felspathic sandstone and conglomerate; some gray shale*	STRATHLORNE MEMBER (300 m thick) *Gray siltstone, shale and sandstone; some impure limestone; some thin red beds and conglomerate* CONFORMABLE	STRATHLORNE FORMATION (about 600 m thick) *Gray and dark gray shale and siltstone, gray sandstone, limestone breccia, some red beds, rare conglomerate*	FRIARS COVE FORMATION *Massive gray sandstone, rippled sandstone, gray shale, dolomite, dolomitic sandstone, stromatolitic dolomite in southeast, minor red beds and arkosic grit, gray quartz arenite at top* *Gray conglomerate and sandstone at base* SHARP TO GRADATIONAL BASE
		CRAIGNISH FORMATION (up to 2400 m thick) *Red siltstone, sandstone and conglomerate; some gray siltstone and sandstone (Skye River Member)* *Gray arkosic sandstone and conglomerate (McLoed Member)* *Gray and red sandstone, conglomerate and red siltstone (Graham River Member)*	CRAIGNISH FORMATION (up to 1620 m thick) *Red and gray-red arkosic conglomerate, sandstone and siltstone; gray sandstone, some gray shale*	SNAKES BIGHT FORMATION *Thick black shales with gray siltstones, sandstones, ferruginous dolomites and thick gray sandstones minor quartz-dolomite pebble conglomerate* *Bedded black shale, gray siltstone, gray sandstone (turbidites) slump deposits, laminates, nodular and bedded dolomite* *Black shale* TECTONIC BOUNDARY
MEMRAMCOOK FORMATION (Up to 2100 m thick) Upper Devonian to Lower Carboniferous *Red shale, siltstone and conglomerate* UNCONFORMITY	UNCONFORMITY	FISSETT BROOK FORMATION (240 m to 450 m) (Lower Carboniferous - Upper Devonian?) *Greenish red conglomerate, red and gray siltstone, andesite, rhyolite, agglomerate*	FISSETT BROOK FORMATION *Basalt, rhyolite, conglomerate derived from basement and volcanics, red sandstone* UNCONFORMITY	KENNEL'S BROOK FORMATION *Gray siltstone, mudstone, very fine sandstone, some red siltstone, nodular and laminated limestone* *Gray and red sandstone, red and some gray, cleaved siltstone* *Gray sandstone, gray conglomerate, minor red beds*

Table 2: Compilation of stratigraphic units and lithology from the Moncton, Horton and Anguille Groups in the Maritimes Basin showing general similarities of stratigraphic succession in each group. No time correlation is intended.

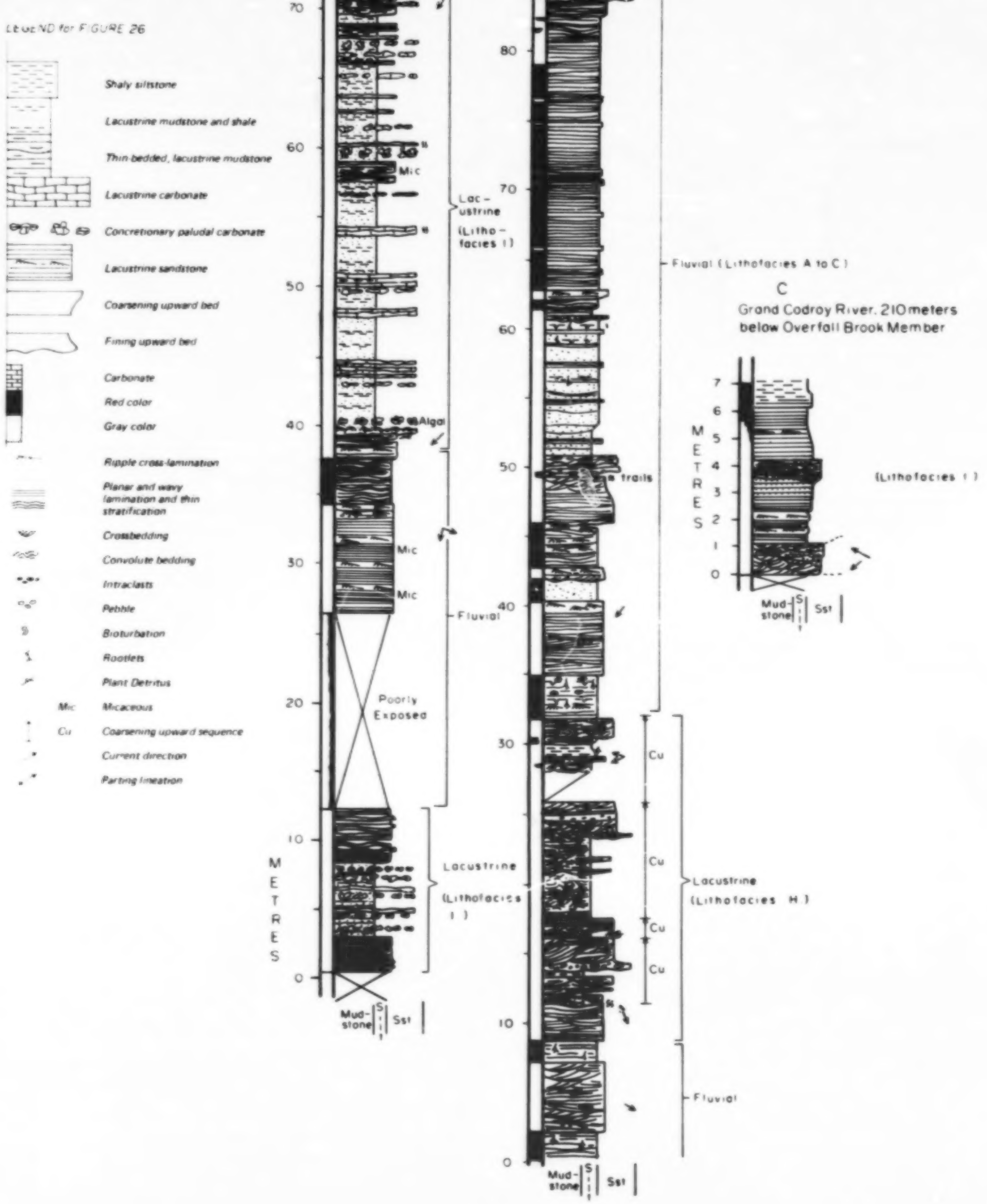
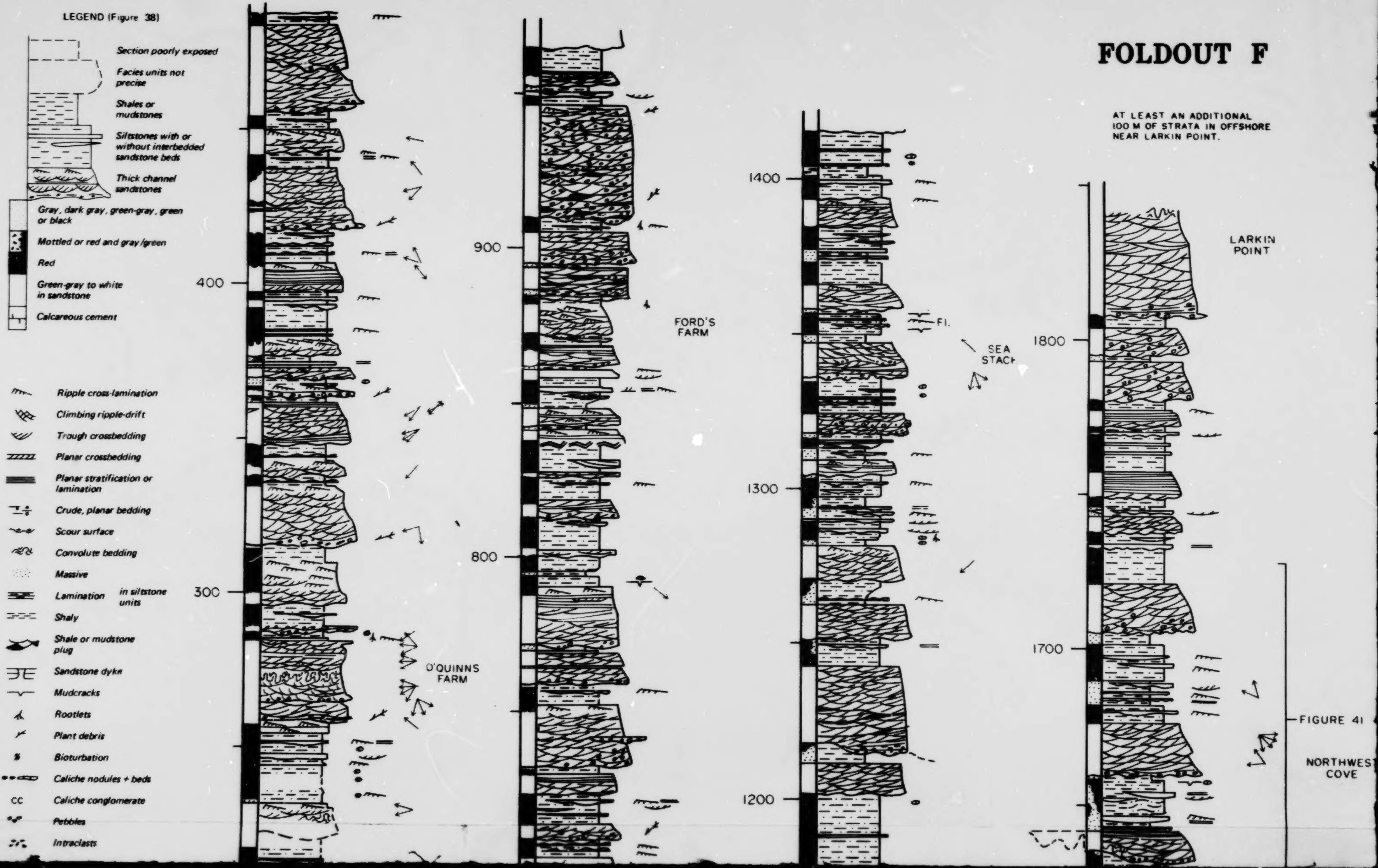
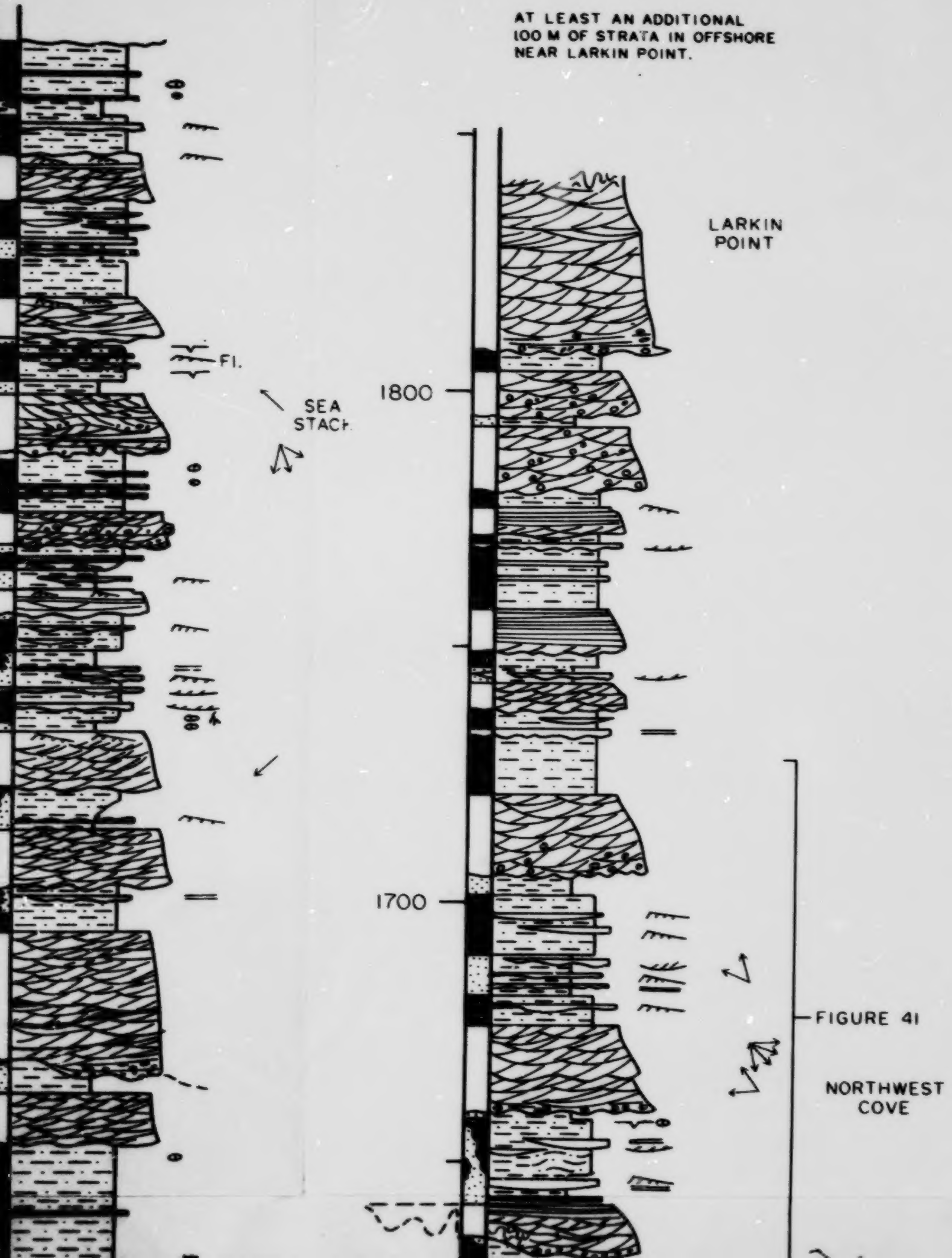

LEGEND for FIGURE 26
Shaly siltstone
Lacustrine mudstone and shale
Thin-bedded, lacustrine mudstone
Lacustrine carbonate
Concretionary paludal carbonate
Lacustrine sandstone
Coarsening upward bed
Fining upward bed
Carbonate
Red color
Gray color
Ripple cross-lamination
Planar and wavy lamination and thin stratification
Crossbedding
Convolute bedding
Intraclasts
Pebble
Bioturbation
Rootlets
Plant Detritus
Mic Micaceous
Cu Coarsening upward sequence
Current direction
Parting lineation
METRES
Mic
Algal
Lac-ustrine (Litho-facies I)
Fluvial
Poorly Exposed
Lacustrine (Lithofacies I)
Mud-stone
Silt
Sst
trails
Fluvial (Lithofacies A to C)
Cu
Lacustrine (Lithofacies H)
Fluvial
C
Grand Codroy River, 210 meters below Overfall Brook Member
(Lithofacies I)
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7

Figure 26: Sections in lacustrine deposits of the Mollichignick Member. The lacustrine units of mudstone, carbonate and micaceous sandstones intercalate with fine redbeds deposited as distal alluvium (sections A and B). Section C illustrates marginal lacustrine sandstones. Scale of sections A and B is different from C. Location of sections within type section shown on Figure 21.

FOLDOUT F


LEGEND (Figure 38)
Section poorly exposed
Facies units not precise
Shales or mudstones
Siltstones with or without interbedded sandstone beds
Thick channel sandstones
Gray, dark gray, green-gray, green or black
Mottled or red and gray/green
Red
Green-gray to white in sandstone
Calcareous cement
Ripple cross-lamination
Climbing ripple-drift
Trough crossbedding
Planar crossbedding
Planar stratification or lamination
Crude, planar bedding
Scour surface
Convolute bedding
Massive
Lamination
in siltstone units
Shaly
Shale or mudstone plug
Sandstone dyke
Mudcracks
Rootlets
Plant debris
Bioturbation
Caliche nodules + beds
CC
Caliche conglomerate
Pebbles
Intraclasts
400
300
O'QUINNS FARM
900
800
FORD'S FARM
1400
1300
1200
Fl.
SEA STACK
AT LEAST AN ADDITIONAL 100 M OF STRATA IN OFFSHORE NEAR LARKIN POINT.
LARKIN POINT
1800
1700
FIGURE 41
NORTHWEST COVE

FOLDOUT F



AT LEAST AN ADDITIONAL 100 M OF STRATA IN OFFSHORE NEAR LARKIN POINT.

Fl.
SEA STACK
1800
1700
LARKIN POINT
FIGURE 41
NORTHWEST COVE

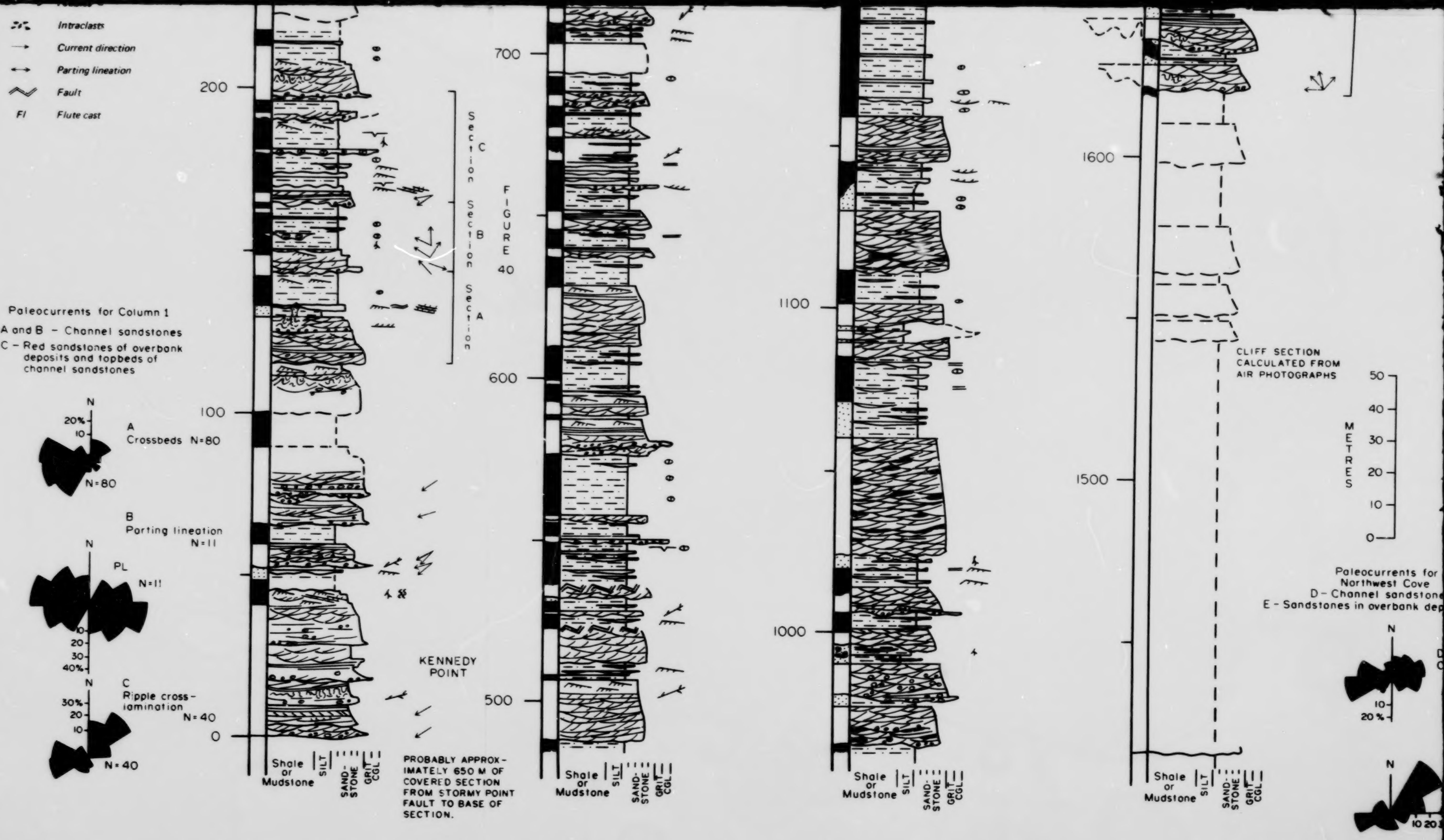
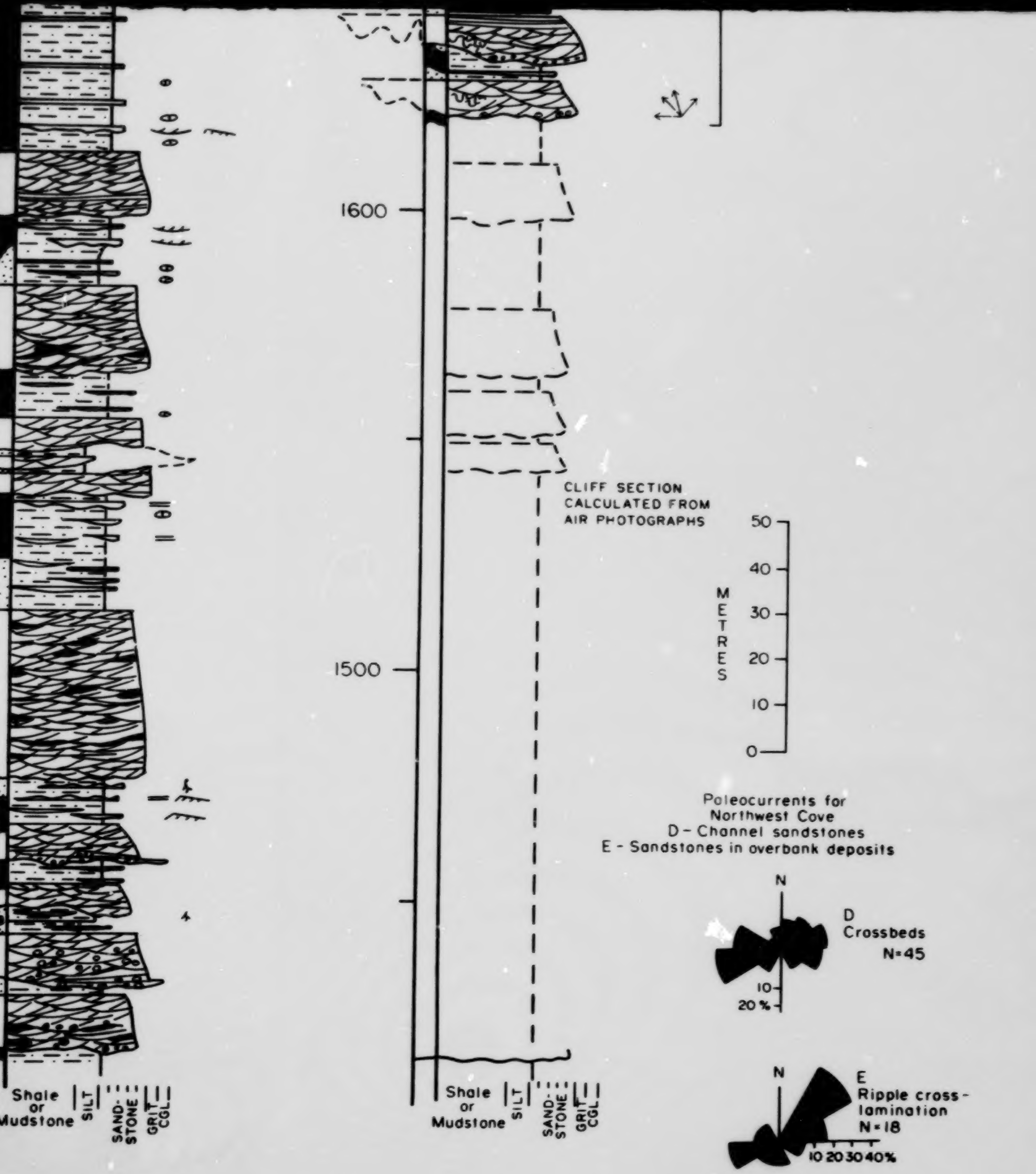

Intraclasts
Current direction
Parting lineation
Fault
Fl Flute cast
Paleocurrents for Column 1
A and B - Channel sandstones
C - Red sandstones of overbank deposits and topbeds of channel sandstones
A Crossbeds N=80
B Parting lineation N=11
C Ripple cross-lamination N=40
Section C
Section B
Section A
FIGURE 40
KENNEDY POINT
PROBABLY APPROXIMATELY 650 M OF COVERED SECTION FROM STORMY POINT FAULT TO BASE OF SECTION.
CLIFF SECTION CALCULATED FROM AIR PHOTOGRAPHS
METRES
Paleocurrents for Northwest Cove
D - Channel sandstone
E - Sandstones in overbank dep
Shale or Mudstone
SILT
SAND-STONE
GRIT
CGL
0
100
200
500
600
700
1000
1100
1500
1600

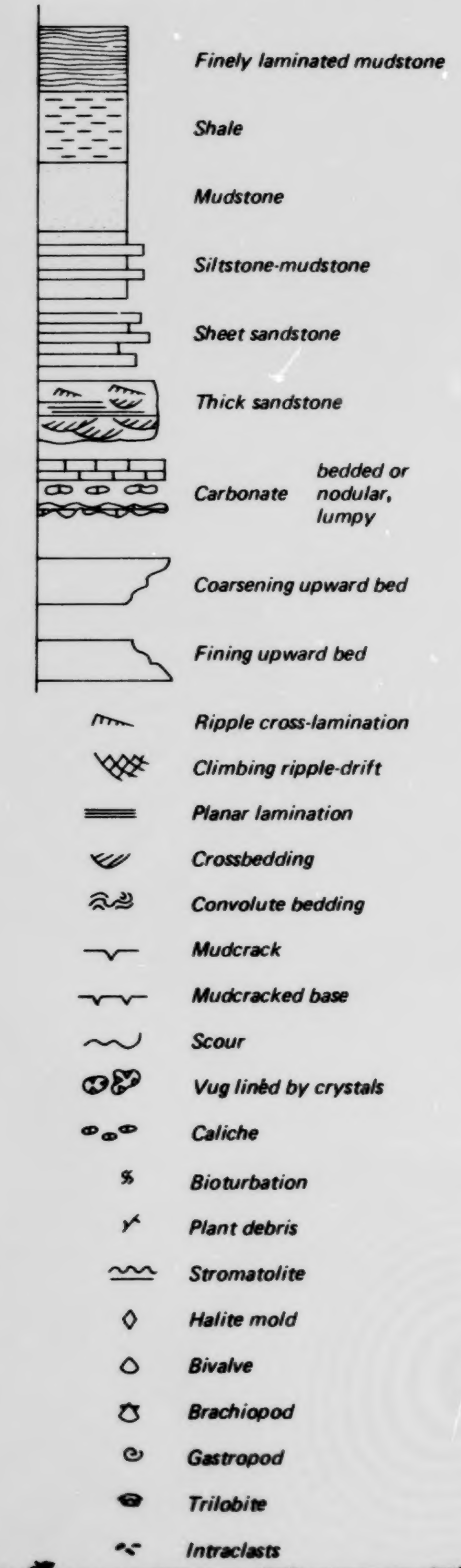
Figure 38: Type section through the Searston Formation from Kennedy Point to Larkin Point; paleocurrent rose diagrams for column 1 and Northwest Cove area also illustrated.


1600
1500
CLIFF SECTION
CALCULATED FROM
AIR PHOTOGRAPHS
METRES
50
40
30
20
10
0
Paleocurrents for
Northwest Cove
D - Channel sandstones
E - Sandstones in overbank deposits
N
D
Crossbeds
N=45
10
20 %
N
E
Ripple cross-
lamination
N=18
10 20 30 40%
Shale
or
Mudstone
SILT
SAND-
STONE
GRIT
CGL
Shale
or
Mudstone
SILT
SAND-
STONE
GRIT
CGL

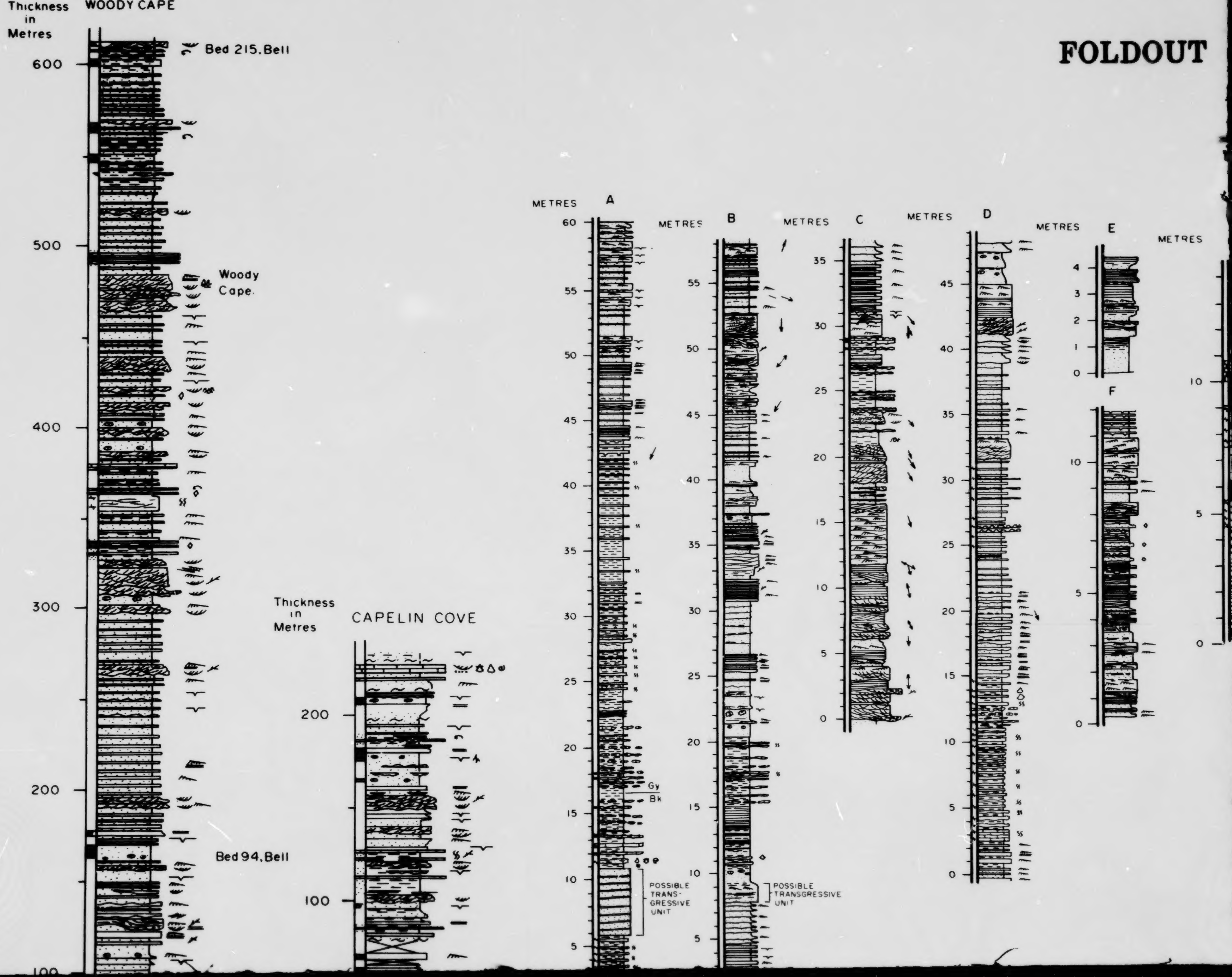
t to Larkin Point; paleocurrent rose diagrams for

FOLDOUT

LEGEND FOR FIGURES 36 & 37

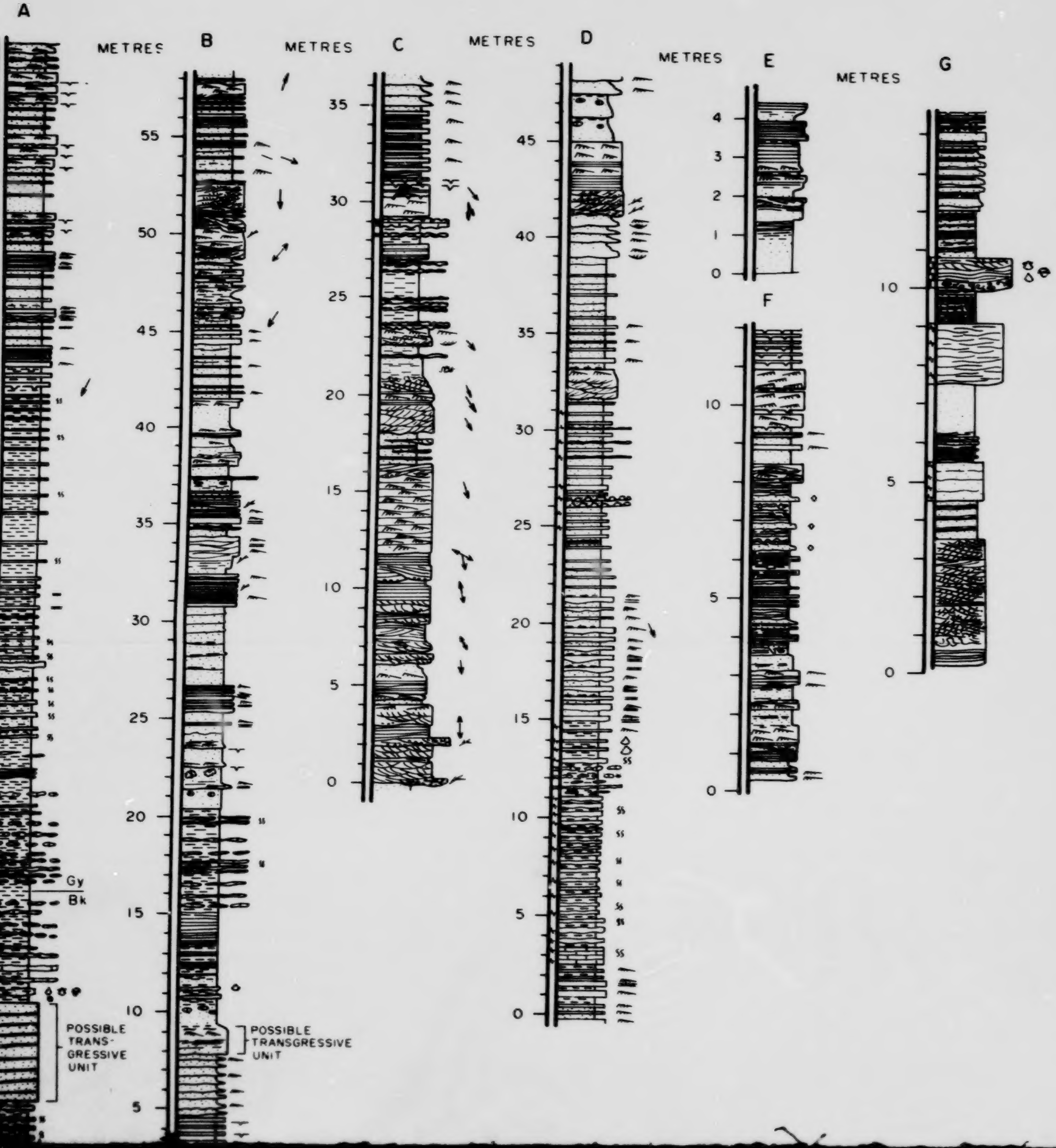


Finely laminated mudstone
Shale
Mudstone
Siltstone-mudstone
Sheet sandstone
Thick sandstone
Carbonate
bedded or
nodular,
lumpy
Coarsening upward bed
Fining upward bed
Ripple cross-lamination
Climbing ripple-drift
Planar lamination
Crossbedding
Convolute bedding
Mudcrack
Mudcracked base
Scour
Vug lined by crystals
Caliche
Bioturbation
Plant debris
Stromatolite
Halite mold
Bivalve
Brachiopod
Gastropod
Trilobite
Intraclasts



Thickness in Metres
WOODY CAPE
Bed 215, Bell
600
500
Woody Cape.
400
300
200
Bed 94, Bell
100
Thickness in Metres
CAPELIN COVE
200
100
METRES
A
60
55
50
45
40
35
30
25
20
15
10
5
Gy
Bk
POSSIBLE TRANS-GRESSIVE UNIT
METRES
B
55
50
45
40
35
30
25
20
15
10
5
POSSIBLE TRANSGRESSIVE UNIT
METRES
C
35
30
25
20
15
10
5
0
METRES
D
45
40
35
30
25
20
15
10
5
0
METRES
E
4
3
2
1
0
F
10
5
0
METRES
10
5
0

FOLDOUT E


A
B
C
D
E
F
G
METRES
METRES
METRES
METRES
METRES
Gy
Bk
POSSIBLE TRANS-GRESSIVE UNIT
POSSIBLE TRANSGRESSIVE UNIT
ss

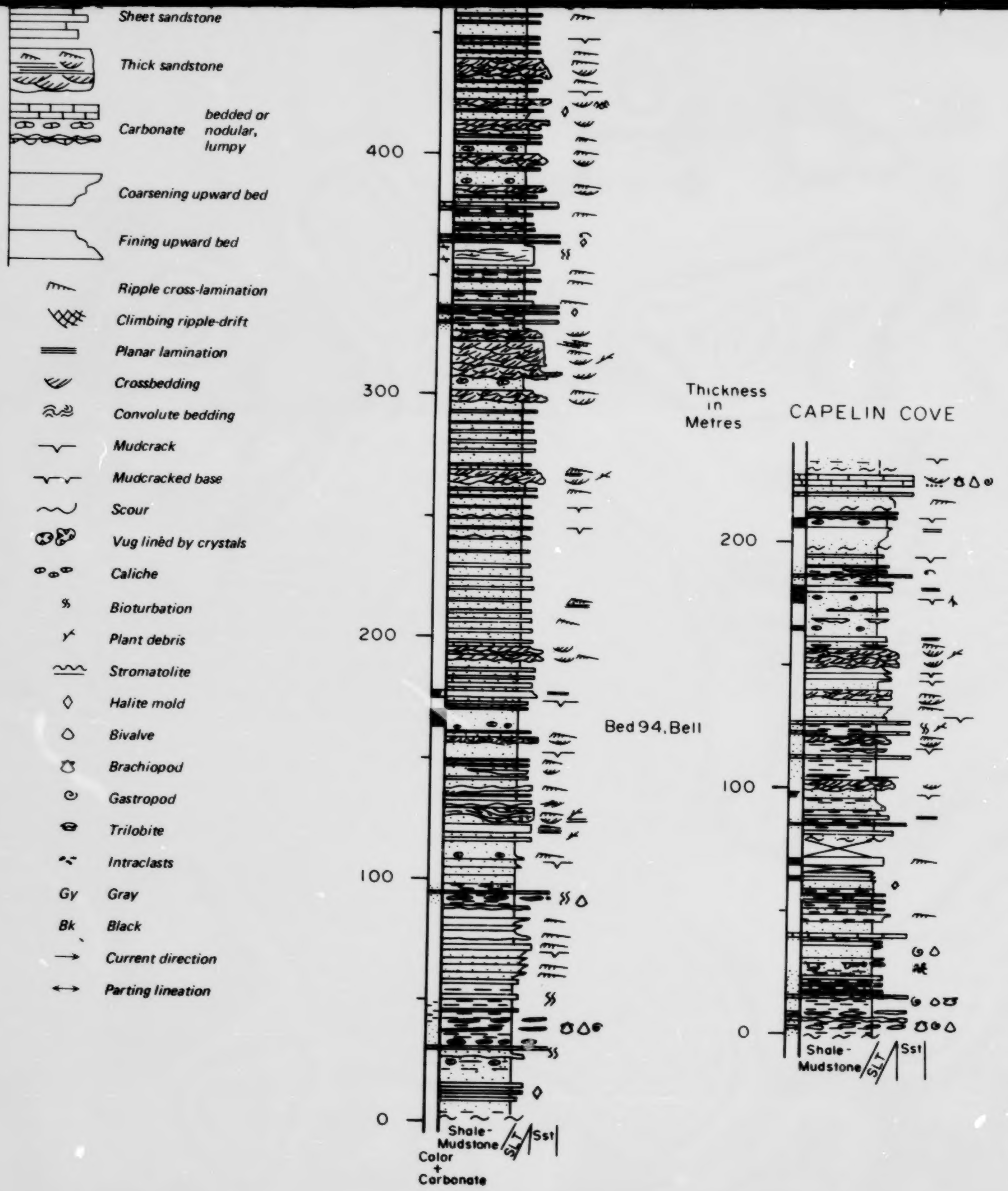

Sheet sandstone
Thick sandstone
Carbonate
bedded or nodular, lumpy
Coarsening upward bed
Fining upward bed
Ripple cross-lamination
Climbing ripple-drift
Planar lamination
Crossbedding
Convolute bedding
Mudcrack
Mudcracked base
Scour
Vug lined by crystals
Caliche
Bioturbation
Plant debris
Stromatolite
Halite mold
Bivalve
Brachiopod
Gastropod
Trilobite
Intraclasts
Gy Gray
Bk Black
Current direction
Parting lineation
400
300
200
100
0
Bed 94, Bell
Shale-Mudstone
SLT
Sst
Color + Carbonate
Thickness in Metres
CAPELIN COVE
200
100
0
Shale-Mudstone
SLT
Sst

Figure 36: Generalized section of the Woody Cape Formation type section north of Woody Cape and an incompleted section in Capelin Cove.

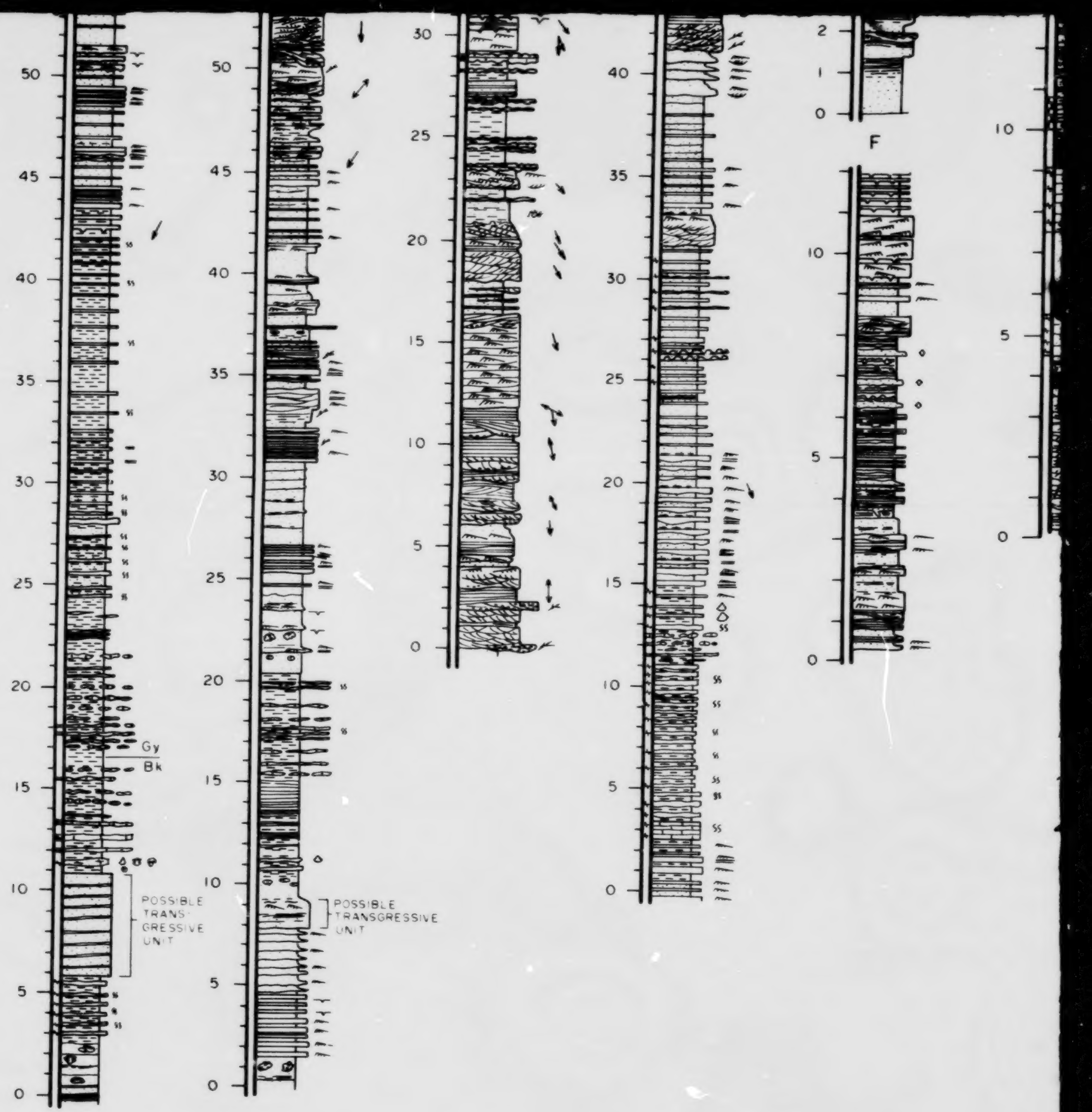
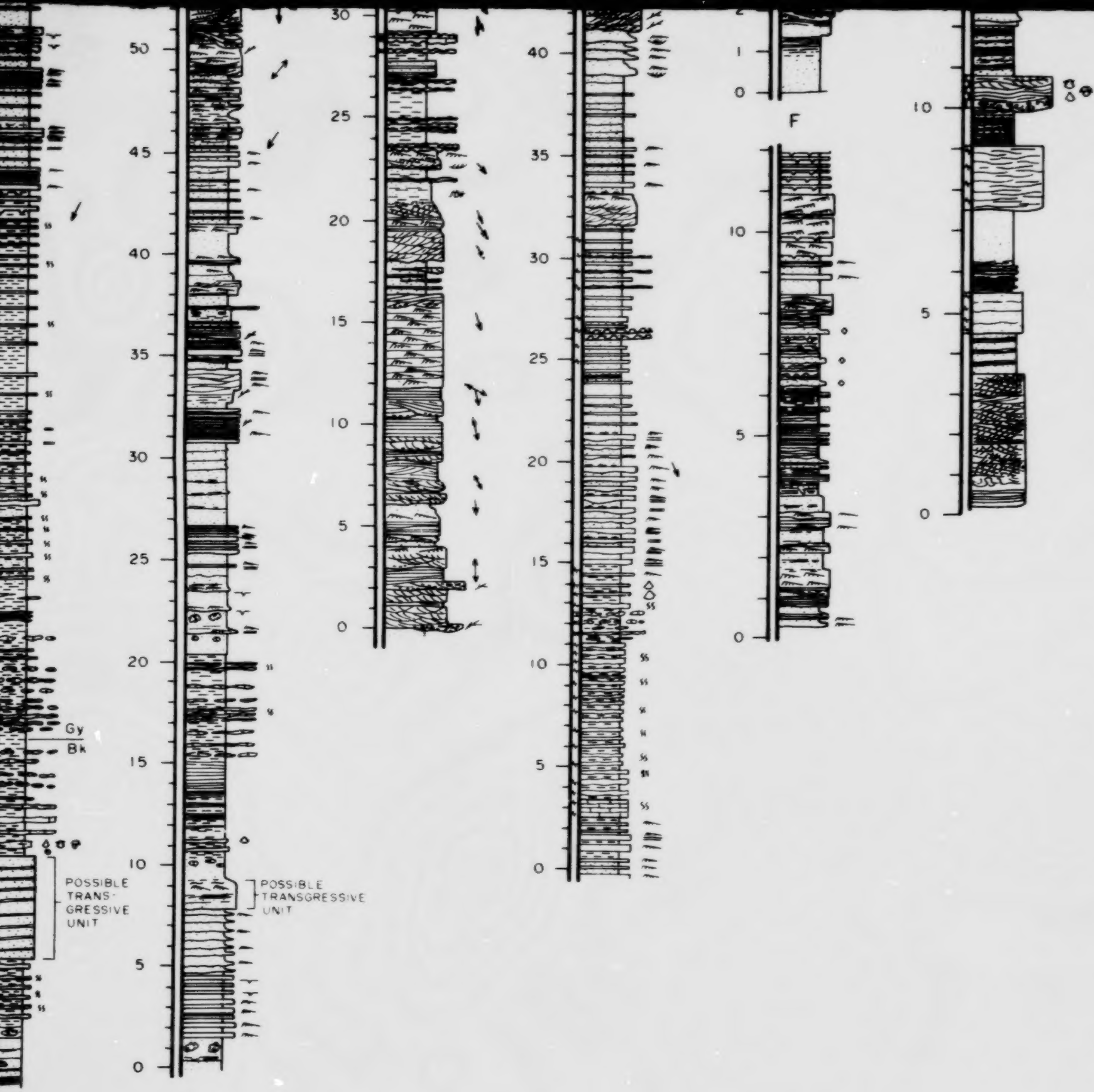
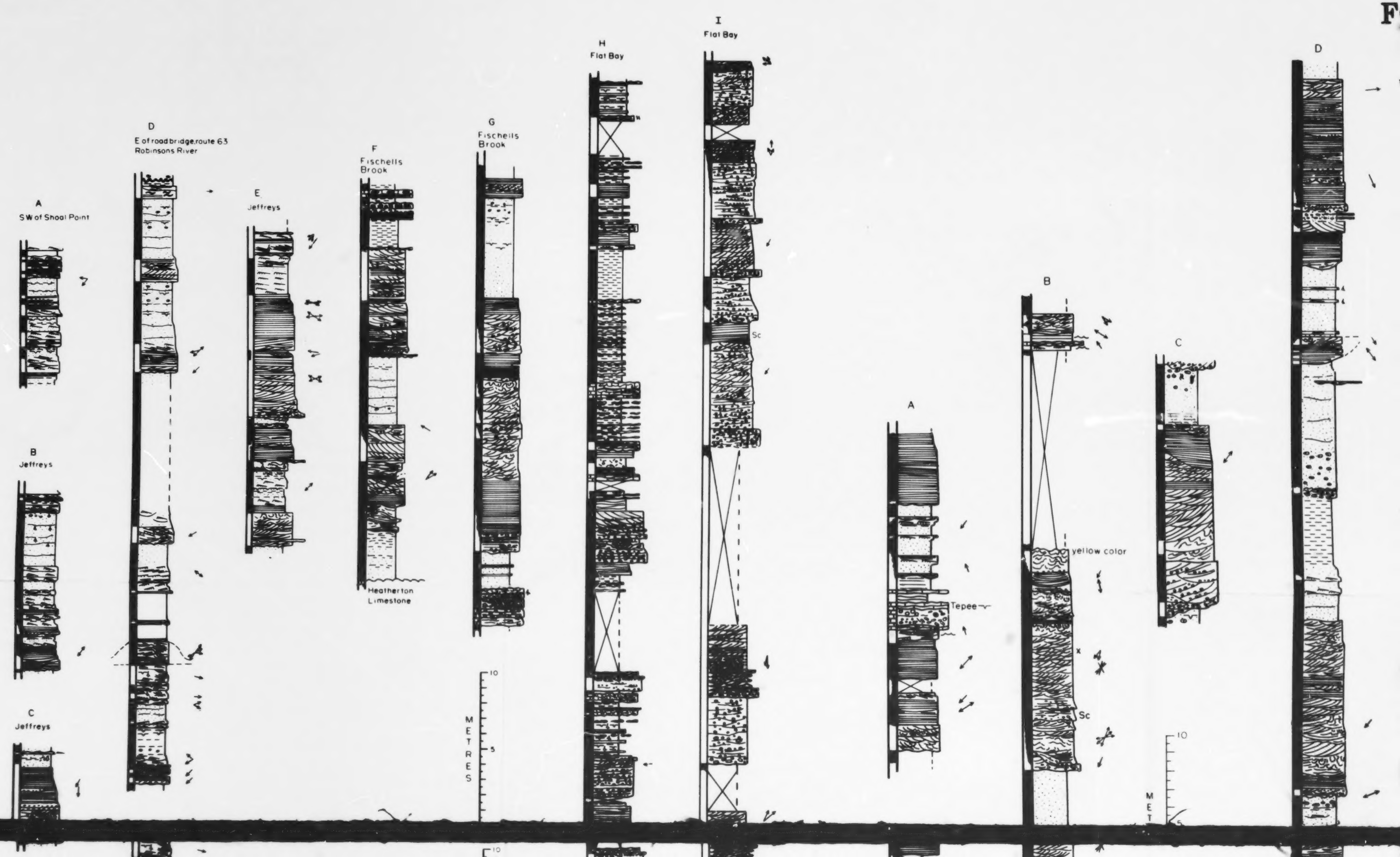

50
45
40
35
30
25
20
15
10
5
0
Gy
Bk
POSSIBLE TRANSGRESSIVE UNIT
POSSIBLE TRANSGRESSIVE UNIT
F
2
1
0
10
5

Figure 37: Detailed sections of intervals of the Woody Cape Formation. Sections A to D arranged in ascending order; E to G taken from various sections to illustrate in more detail the bedded mudstones and siltstones of the f Section A shows gradually shoaling upward marine sequence close to the base of the formation. Other s demonstrate gradation from offshore or lagoon to emergent mudflat or delta plain as at the base of section Coarsening-upward sequences from mudstones up into sheeted and some channelled sandstones occur ne of section A and in section B. Fining-upward distributary channel sandstones occur, in two units in sec top of section B and at the base of section C where they are overlain by marsh flat muds and carbonate. contains laminated mudstones of lithofacies C; section D shows characteristic bedded mudstones and of delta plain; section G includes calcarenite and calcirudite of lithofacies G. Section G from Capelin other sections from type section.

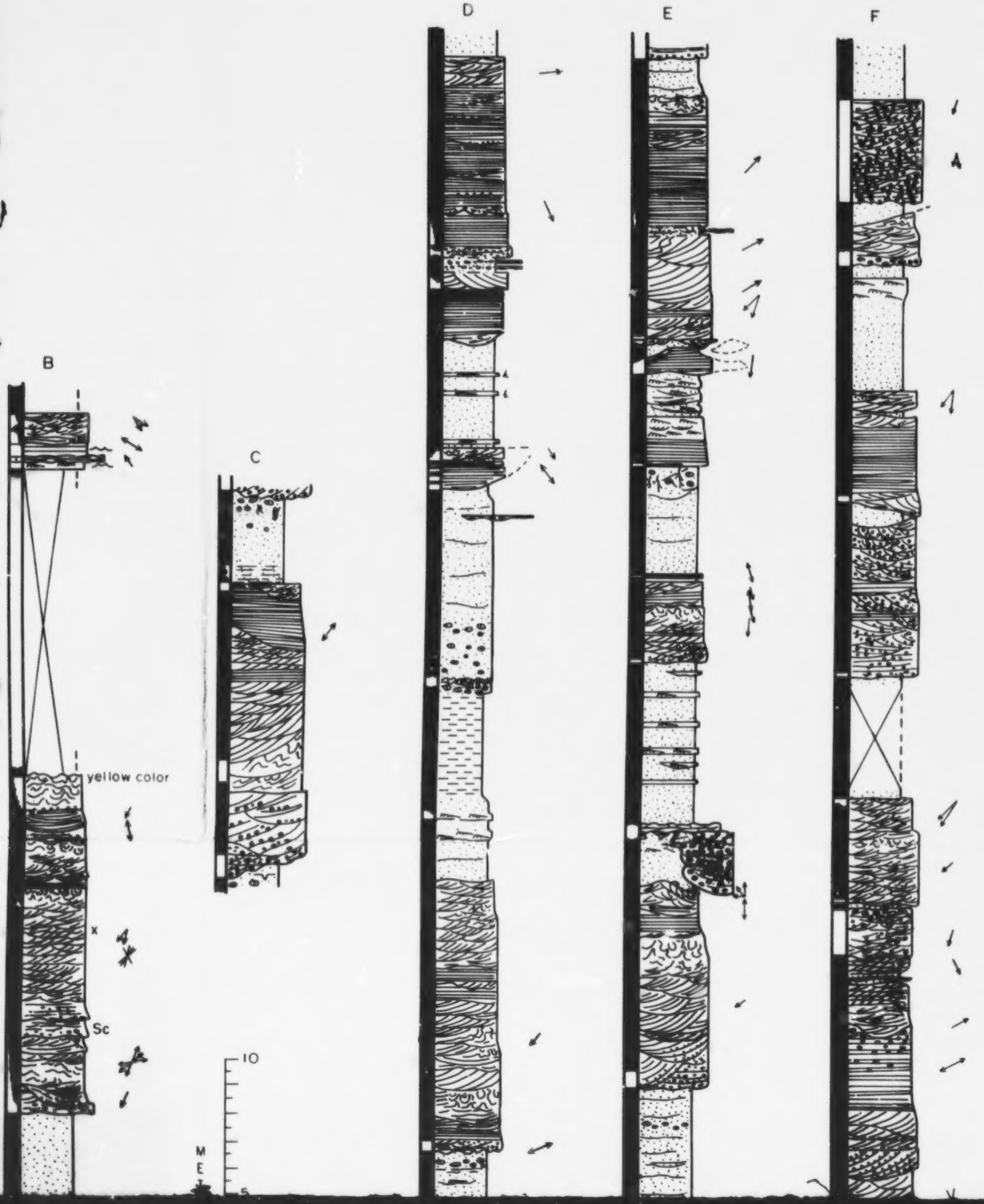


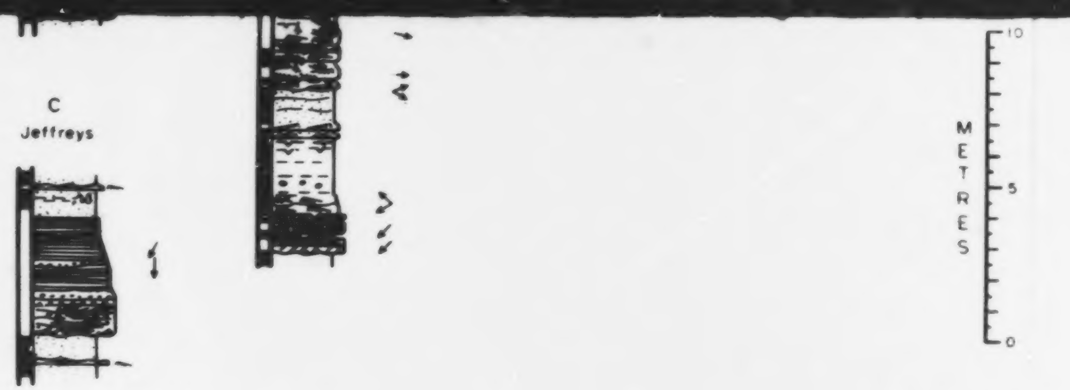
e 37: Detailed sections of intervals of the Woody Cape Formation. Sections A to D arranged in ascending order. Sections E to G taken from various sections to illustrate in more detail the bedded mudstones and siltstones of the formation. Section A shows gradually shoaling upward marine sequence close to the base of the formation. Other sequences demonstrate gradation from offshore or lagoon to emergent mudflat or delta plain as at the base of section B and D. Coarsening-upward sequences from mudstones up into sheeted and some channelled sandstones occur near the top of section A and in section B. Fining-upward distributary channel sandstones occur, in two units in section D, at top of section B and at the base of section C where they are overlain by marsh flat muds and carbonate. Section F contains laminated mudstones of lithofacies C; section D shows characteristic bedded mudstones and siltstones of delta plain; section G includes calcarenite and calcirudite of lithofacies G. Section G from Capelin Cove; all other sections from type section.

F


A
SW of Shoal Point
B
Jeffreys
C
Jeffreys
D
E of road bridge, route 63
Robinsons River
E
Jeffreys
F
Fischells
Brook
Heatherton
Limestone
G
Fischells
Brook
10
5
METRES
10
H
Flat Bay
I
Flat Bay
Sc
A
Tepee
B
yellow color
x
Sc
C
10
5
MET
D

FOLDOUT D


D
E
F
B
C
yellow color
x
Sc
10
M
E
T
5


C
Jeffreys
METRES
10
5
0

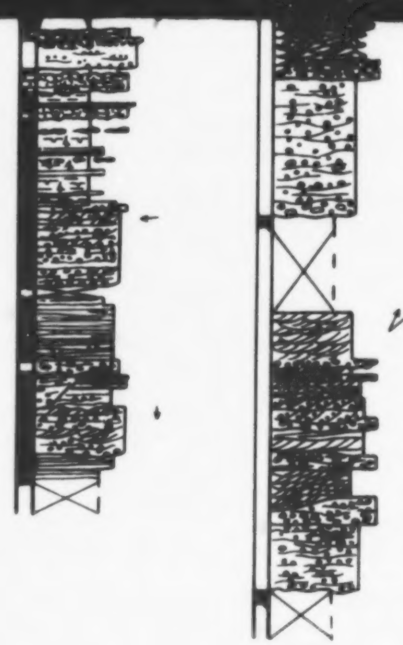


Figure 23: Detailed sedimentary sections of nonmarine lithofacies in the redbeds of the upper part of the Jeffrey's Village Member, St. George's Bay lowlands. Sections A to D, distal alluvial plain; sections E to G, channel sandstones; sections F and H, playa flat; sections K and I, braided stream, distal alluvial fan. Gray stromatolitic limestones occur above sandy braided stream and red playa flat deposits in section F. Location of detailed sedimentological sections of this figure shown on Figure 20.

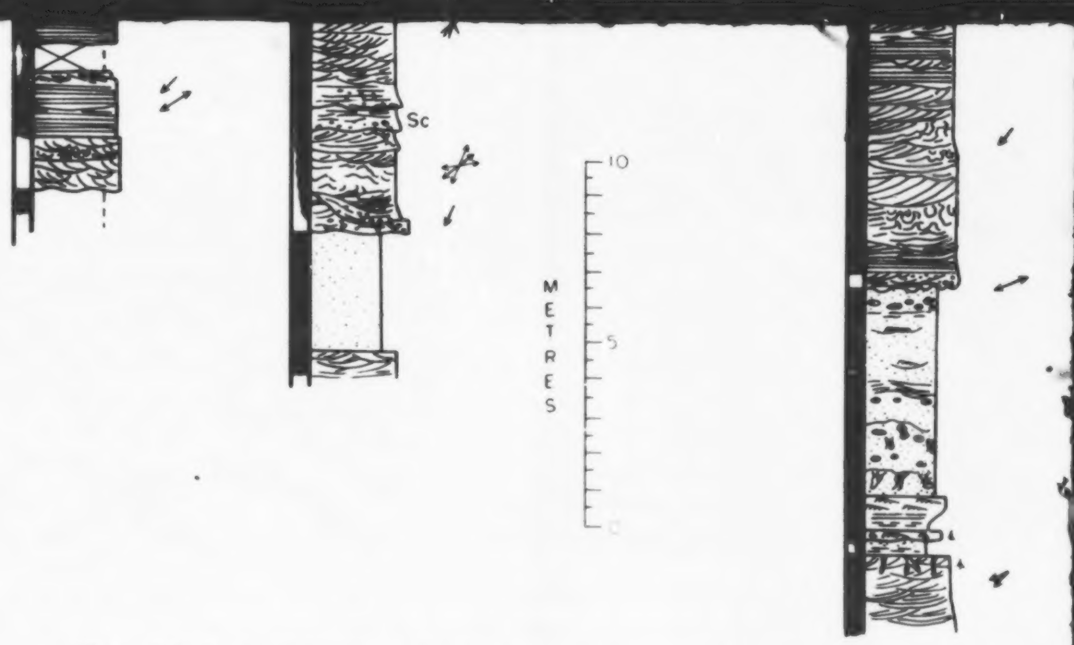
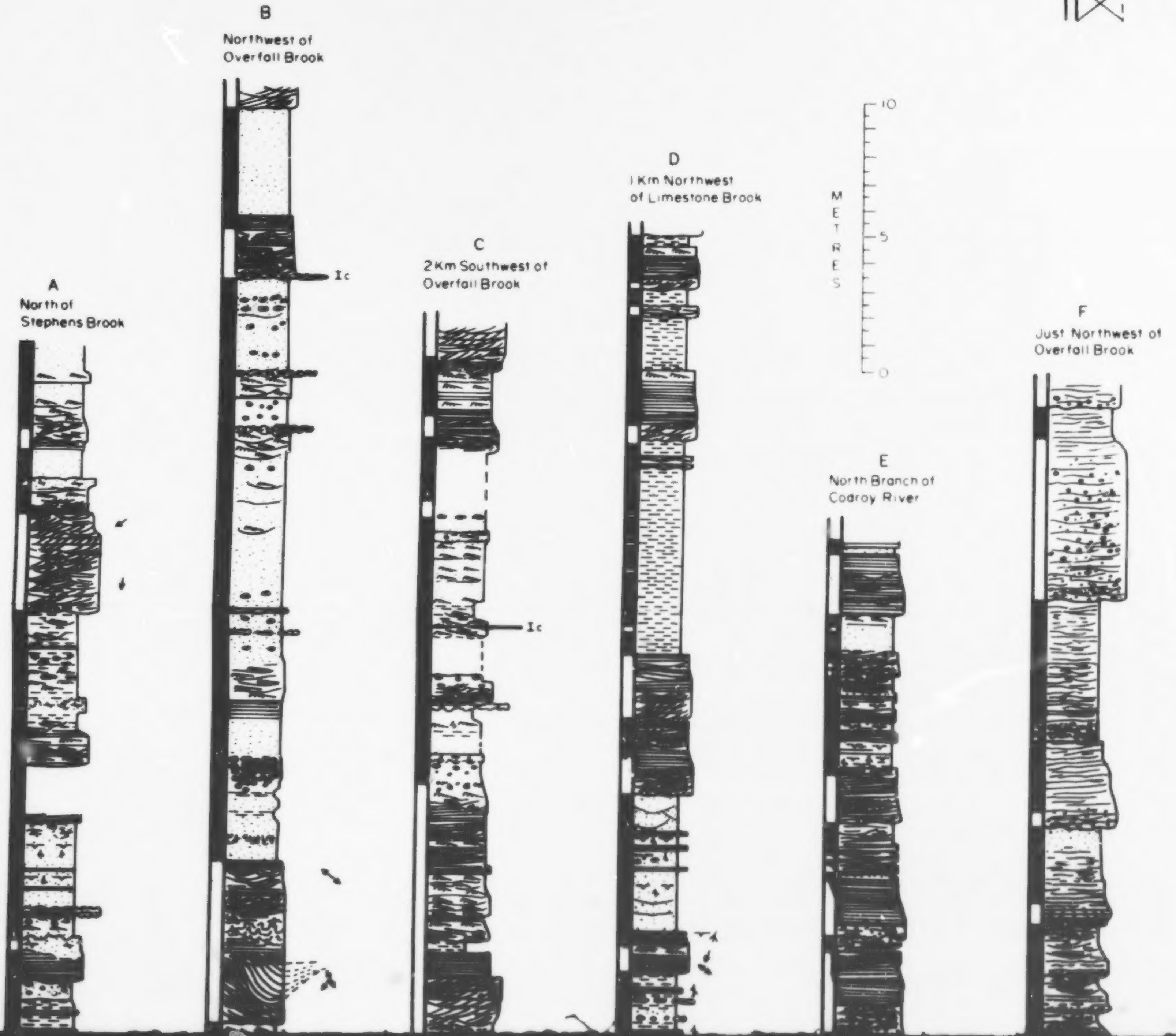
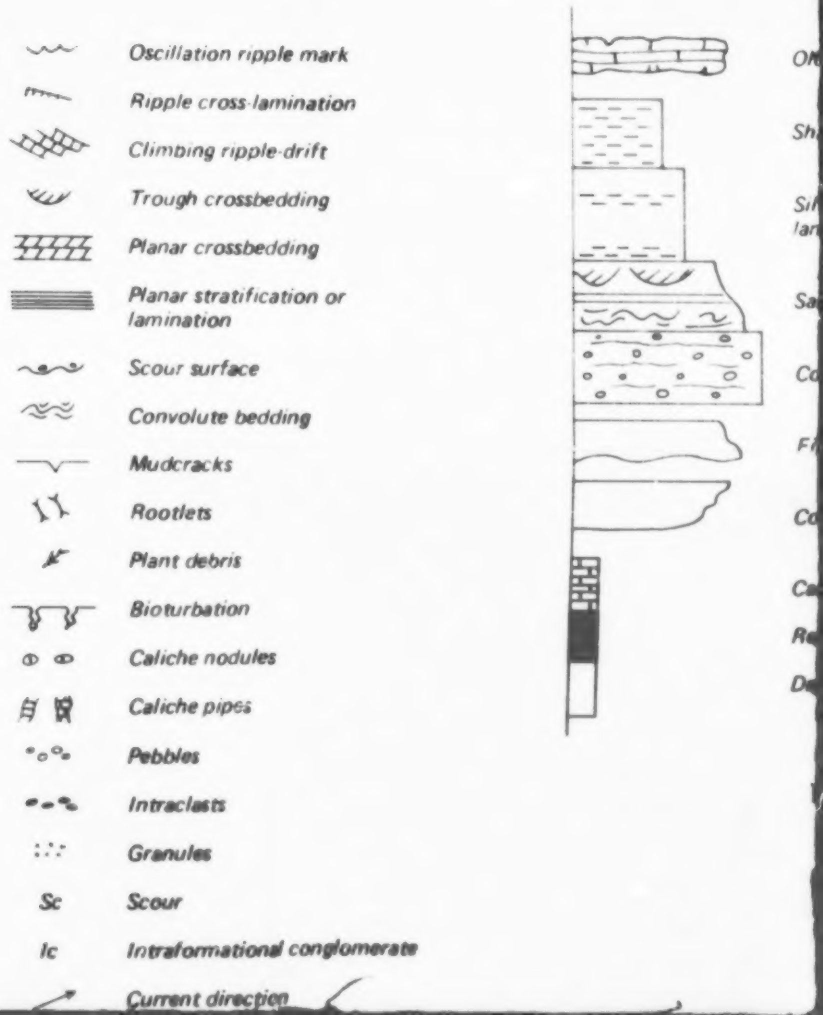
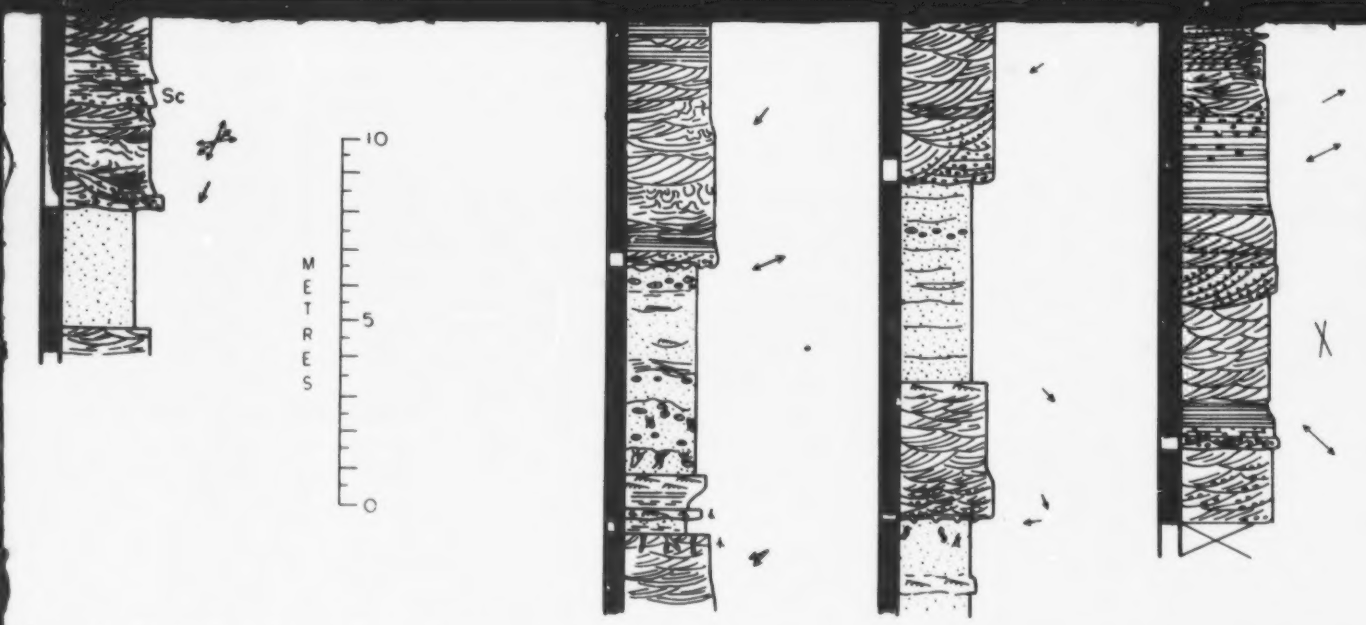

Sc
METRES
10
5
0

Figure 24: Detailed sections of redbeds from the Highlands Member, St. George's Bay limestone units with ripple-bedded, clean sandstones in sections A and B.


A
North of Stephens Brook
B
Northwest of Overfall Brook
Ic
C
2 Km Southwest of Overfall Brook
Ic
D
1 Km Northwest of Limestone Brook
METRES
10
5
0
E
North Branch of Codroy River
F
Just Northwest of Overfall Brook

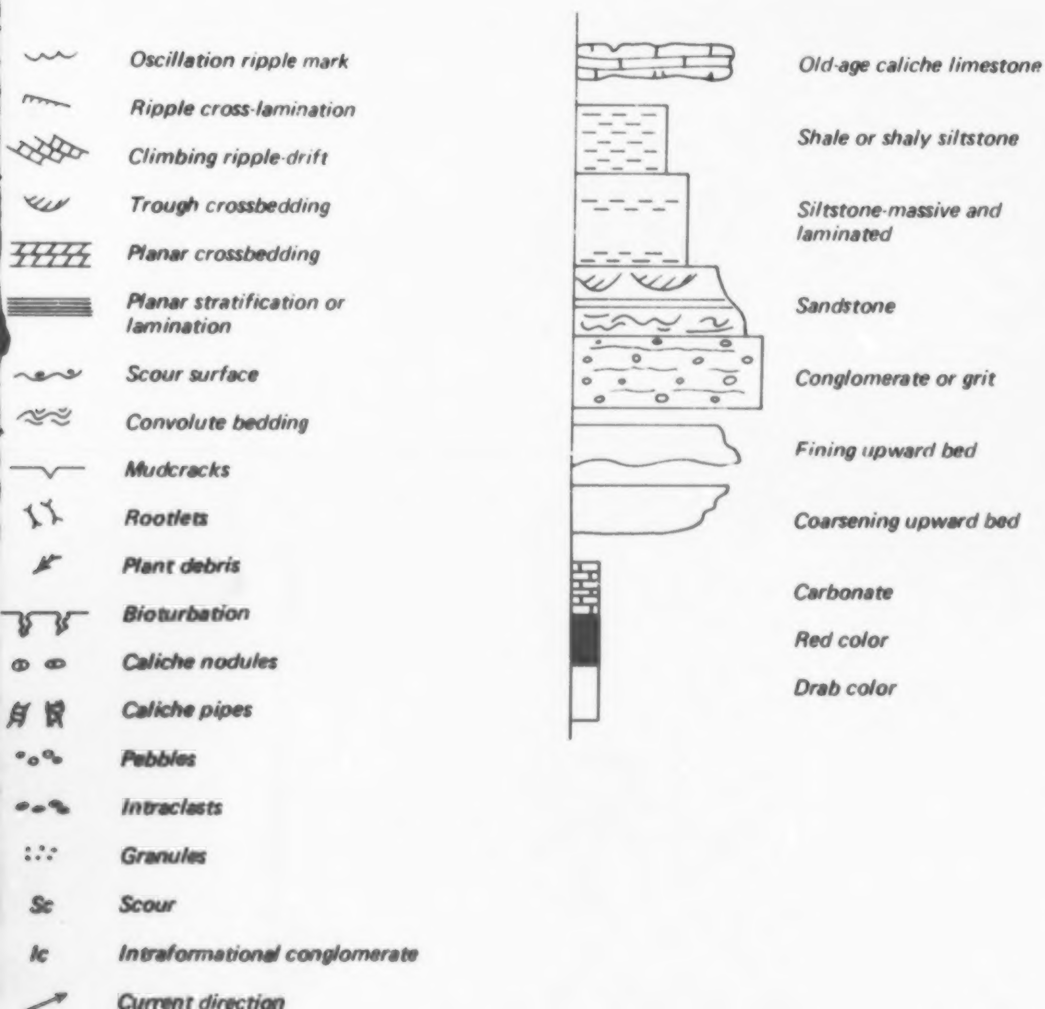
LEGEND FOR FIGURES 23, 24 & 25


Oscillation ripple mark
Ripple cross-lamination
Climbing ripple-drift
Trough crossbedding
Planar crossbedding
Planar stratification or lamination
Scour surface
Convolute bedding
Mudcracks
Rootlets
Plant debris
Bioturbation
Caliche nodules
Caliche pipes
Pebbles
Intraclasts
Granules
Sc
Scour
Ic
Intraformational conglomerate
Current direction


Sc
10
METRES
5
0

iled sections of redbeds from the Highlands Member, St. George's Bay (see figure 20 for location). Marinal (?) one units with ripple-bedded, clean sandstones in sections A and B.

LEGEND FOR FIGURES 23, 24 & 25


Oscillation ripple mark
Ripple cross-lamination
Climbing ripple-drift
Trough crossbedding
Planar crossbedding
Planar stratification or lamination
Scour surface
Convolute bedding
Mudcracks
Rootlets
Plant debris
Bioturbation
Caliche nodules
Caliche pipes
Pebbles
Intraclasts
Granules
Sc Scour
Ic Intraformational conglomerate
Current direction
Old-age caliche limestone
Shale or shaly siltstone
Siltstone-massive and laminated
Sandstone
Conglomerate or grit
Fining upward bed
Coarsening upward bed
Carbonate
Red color
Drab color

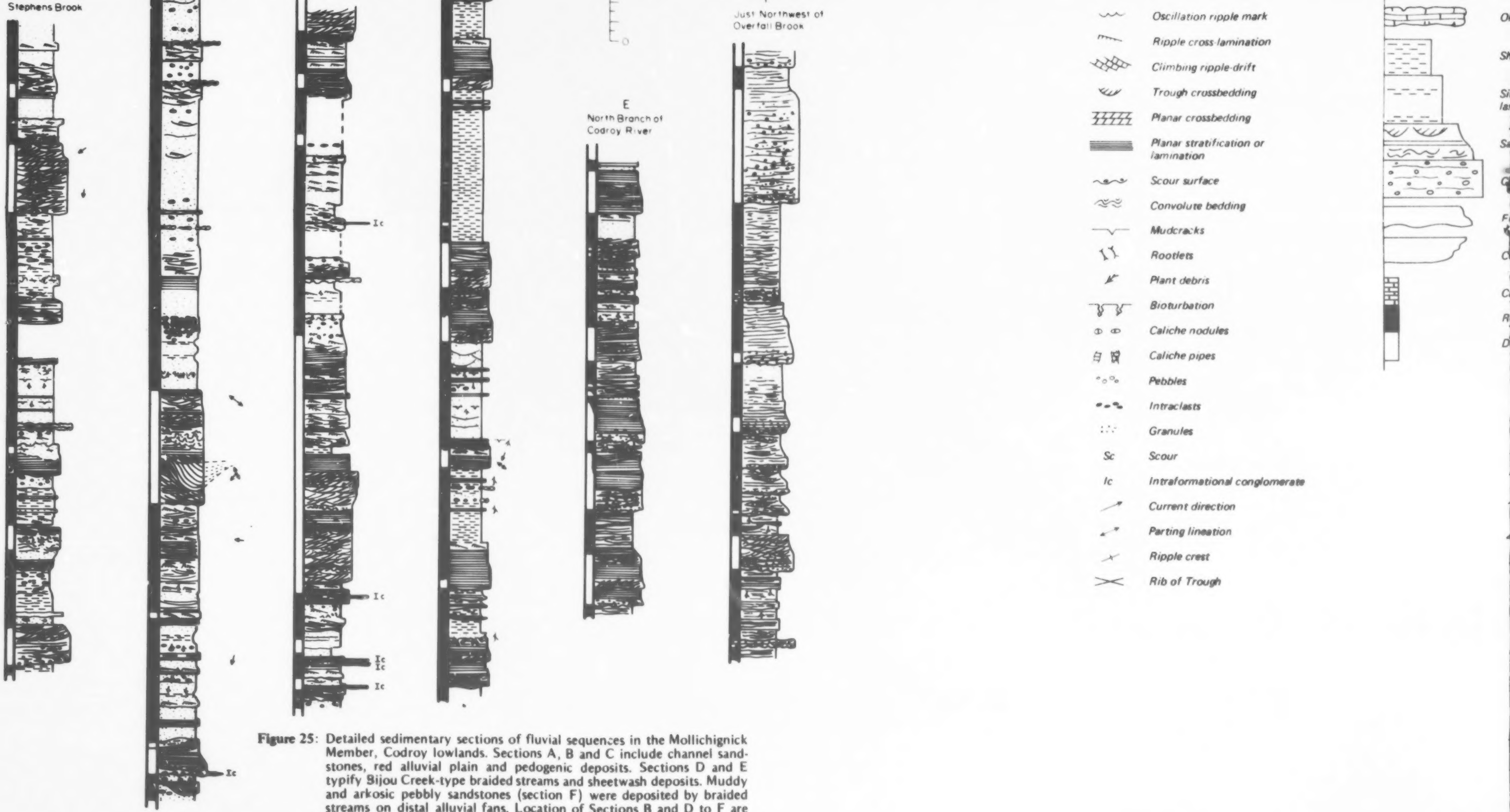
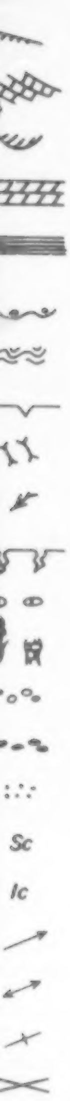
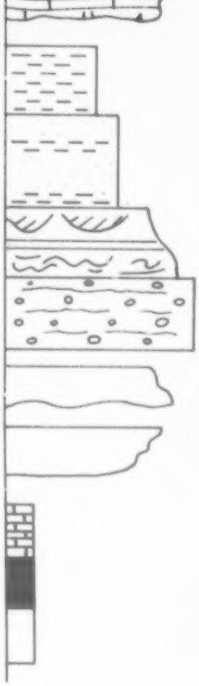

Stephens Brook
Ic
Ic
Ic
Ic
Ic
Ic
0
E
North Branch of Codroy River
Just Northwest of Overfall Brook
Oscillation ripple mark
Ripple cross-lamination
Climbing ripple-drift
Trough crossbedding
Planar crossbedding
Planar stratification or lamination
Scour surface
Convolute bedding
Mudcracks
Rootlets
Plant debris
Bioturbation
Caliche nodules
Caliche pipes
Pebbles
Intraclasts
Granules
Sc
Scour
Ic
Intraformational conglomerate
Current direction
Parting lineation
Ripple crest
Rib of Trough

Figure 25: Detailed sedimentary sections of fluvial sequences in the Mollichignick Member, Codroy lowlands. Sections A, B and C include channel sandstones, red alluvial plain and pedogenic deposits. Sections D and E typify Bijou Creek-type braided streams and sheetwash deposits. Muddy and arkosic pebbly sandstones (section F) were deposited by braided streams on distal alluvial fans. Location of Sections B and D to F are shown on Figure 21.



Oscillation ripple mark
Ripple cross-lamination
Climbing ripple-drift
Trough crossbedding
Planar crossbedding
Planar stratification or lamination
Scour surface
Convolute bedding
Mudcracks
Rootlets
Plant debris
Bioturbation
Caliche nodules
Caliche pipes
Pebbles
Intraclasts
Granules
Scour
Intraformational conglomerate
Current direction
Parting lineation
Ripple crest
Rib of Trough



Old-age caliche limestone
Shale or shaly siltstone
Siltstone-massive and laminated
Sandstone
Conglomerate or grit
Fining upward bed
Coarsening upward bed
Carbonate
Red color
Drab color

POOR

QUALITY

ORIGINAL